# DEVELOPING A PREDATION INDEX AND EVALUATING WAYS TO REDUCE SALMONID LOSSES TO PREDATION IN THE COLUMBIA RIVER BASIN

**Annual Progress Report**

**August 1988 - September 1989**


**Edited By**

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**Oregon State University**
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## EXECUTIVE SUMMARY

We report on our progress from August 1988 through September 1989 on developing a predation index and evaluating ways to reduce juvenile salmonid losses to predation in the Columbia River Basin. The study is a cooperative effort by the Oregon Department of Fish and Wildlife (ODFW), Oregon State University (OSU) and University of Washington- Fisheries Research Institute (UW-FRI) and Center for Quantitative Science (VW-CQS). ODFW is the lead agency and has sub-contracted various tasks and activities to OSU, UW-FRI and VW-CQS based on expertise each would bring to the study. Study objectives of each cooperator are

1. ODFW (Report A) : Develop an index to estimate predation losses of juvenile salmonids ***(Oncorhynchus*** spp) in reservoirs throughout the Columbia River Basin, describe the relationships among predator-caused mortality of juvenile salmonids and physical and biological variables, examine the feasibility of developing bounty, commercial or recreational fisheries on northern squawfish ***(Ptychocheilus oregonensis)*** and develop a plan to evaluate the efficacy of predator control fisheries.

2. OSU (Report B): Determine the economic feasibility of developing bounty and commercial fisheries for northern squawfish, assist ODFW with evaluating the economic feasibility of recreational fisheries for northern squawfish and assess the economic feasibility of utilizing northern squawfish, carp ***(Cyprinus carpio)*** and suckers ***(Catostomus*** spp)in multispecies fisheries.

3. UW-FRI (Report C): Evaluate commercial technology of various fishing methods for harvesting northern squawfish in Columbia River reservoirs and field test the effectiveness of selected harvesting systems, holding facilities and transportation systems.

4. UW-CQS[1]: Modify the existing Columbia River Ecosystem Model (CREM) to include processes necessary to evaluate effects of removing northern squawfish on their population size structure and abundance, document the ecological processes, mathematical equations and computer (FORTRAN) programming of the revised version of CREM and conduct systematic analyses of various predator removal scenarios, using ***revised*** CREM to generate the simulations.

The detailed objectives and tasks for each cooperator and progress to date are presented in Report A, Appendix A-l.

Highlights of results of our work to date are

### Report A

1. Preliminary results from a questionnaire distributed to fishery professionals in the Columbia River Basin indicate a general perception that predator-caused mortality of juvenile salmonids is greatest in lower Columbia River reservoirs (between Bonneville and McNary dams), but that

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[1] VW-CQS will report finding in the final report.

localized problems exist in the tailraces and forebays of Bonneville, The Dalles, John Day, McNary, Priest Rapids, Ice Harbor and Lower Granite dams.

2. Estimates of absolute abundance based on mark-recapture studies will be imprecise and may only be able to detect orders of magnitude differences among reservoirs. Estimates of northern squawfish abundance in various Columbia and Snake river reservoirs have ranged up to 113,000. If various assumptions of mark-recapture abundance estimators have been seriously violated, estimates of northern squawfish abundance may exceed 400,000 in John Day Reservoir. Density of northern squawfish was 4.4 per hectare in John Day Reservoir, lowest reported in literature.

3. Estimates of relative abundance based on catch per unit effort (CPUE) will be imprecise and may only be able to detect orders of magnitude differences among reservoirs. CPUE of northern squawfish in John Day Reservoir varied by gear, year, month and location indicating that sampling should be designed to capture this inherent variability.

4. Indices based on estimates of available habitat indicate that northern squawfish abundance may vary considerably among Columbia River basin reservoirs. System-wide abundance estimates based on northern squawfish density in John Day Reservoir and length, area and volume of all Columbia River reservoirs ranged from 0.5 million to 1.0 million. Thermal habitat and morphoedaphic indices indicated high variability in potential northern squawfish productivity among reservoirs.

5. Sampling to further refine relationships between physical and biological variables and dynamics of northern squawfish and walleye ***(Stizostedion vitreum vitreum)*** populations yielded 118 northern squawfish and 14 walleye in 165 bottom gill net sets (1-3 hr duration) and 443 northern squawfish by hook and line. Mean CPUE in bottom gill nets was 0.27 northern squawfish per hour and 0.018 walleye per hour. We caught 12.6 northern squawfish per hour by angling from McNary Dam. Mean length, weight and age of northern squawfish caught in bottom gill nets were 345 mm, 564 g and 8 years. Mean length, weight and age of walleye caught in bottom gill nets were 412 mm, 945 g and 4 years. Northern squawfish caught by angling averaged 408-mm long and weighed an average of 979 g. Too few walleye were caught to define walleye and northern squawfish interactions.

6. Planning continues for implementation of predator control fisheries. We describe a test fishery in John Day Reservoir in 1990 to evaluate whether any or all of three components: commercial-bounty, recreational-bounty or dam angling can be implemented system-wide. Gear to be used in the commercial-bounty test fishery in 1990 will be identified by UW-FRI. Approaches to implementing the test fishery in 1990 will be determined by ODFW in collaboration with OSU and UW-FRI.

7. Planning continues for evaluation of predator control fisheries. Given the inherent difficulty in detecting changes in juvenile salmonid survival and isolating causes of changes in adult returns, evaluation of predator control fisheries would initially focus on changes in the predator populations. Responses of predator populations to exploitation would be monitored using simulation modeling based on catch and biological data from the fisheries: supplemented as necessary by evaluation team sampling. Evaluation would be aided by small-scale experiments aimed at defining

cause-effect relationships critical for directing the fisheries in response to changes in predator populations.
Simulation modeling will also be used to examine potential responses of juvenile salmonid mortaility to predator removals.

## Report B

1. Contaminant tests for organics (PCB's, chlordane and DDT derivatives) showed levels below Food and Drug Administration (FDA) action levels indicating northern squawfish are suitable for human consumption. Tests are being conducted for heavy metals (mercury, aluminum, lead and arsenic).

2. Several end uses for northern squawfish were examined. Test marketing in Asian markets and restaurants in Portland and Salem indicated favorable responses to taste and texture, but identified unfamiliarity and boniness as problems. Markets also cited competition with recreationally caught fish in the summer as another problem. Restaurants served northern squawfish steamed, fried or sauteed, pricing dishes between $5.00 and $8.00. Markets sold northern squawfish with head on and gutted and charged from $0.29 to SO.99 per pound. Restaurants and markets expressed interest in a deboned product that could be used for fish cakes and fish balls. Astoria Seafood Lab will try northern squawfish in their de-boning process this fall. A bait dealer reported northern squawfish we delivered to him were readily accepted as crayfish bait; price was $0.10 per pound. Testing of northern squawfish for multiple-use processing (using glands, skin and flesh), as fish meal and as animal feed are ongoing.

3. Transportation of northern squawfish from harvest site to market appears to be no problem. Iced fish trucked over 5 hours were still alive upon delivery from Umatilla to Portland. Live fish survived well in tanks transported on a flat-bed truck. Dead fish mottled in color after awhile, presenting some cosmetic concerns.

4. Regulatory concerns with regards to implementing predator control fisheries are still being identified. Policy and public review processes, environmental impact assessment needs, time frames and schedules are being defined and strategies devised to enable implementation as soon as possible.

5. Alternatives to "squawfish" are being explored with FDA as possible market names for northern squawfish and further testing of carp and suckers as supplemental species in a multiple-species fishery is being conducted. Carp sold well when delivered with northern squawfish to markets. Suckers may have too low a flesh to head and bones ratio for human consumption.

## Report C

1. Gear was initially evaluated and chosen based on three criteria: incidental catch of fish other than northern squawfish, expense if employed by commercial fishing vessels presently used in reservoirs between Bonneville and McNary dams and catch rates relative to those needed to achieve at least 20% exploitation. Given these criteria, four gear were chosen to field test; purse seine, baited long-line, baited pots and bottom gill nets.

2. The purse seine was set in depths greater than 20 feet. No northern squawfish were caught in sets in the main channel near Umatilla and Irrigon. Eighteen sets in the McNary Dam spill basin yielded an average of five northern squawfish per set. Except for American shad ***(Alosa sapidissima)*** there was no mortality of incidentally caught fish.

3. Baited long-lines were tested extensively. In 114 sets (50-75 hooks per line and about 6 hours per set), 523 northern squawfish were caught. This averaged out to 5 squawfish per long-line set or 0.015 per hook-hour or 12 hooks per northern squawfish. Catch "peaked out" at about 5-hour sets. About 73% of catch was northern squawfish; 22% was sturgeon and catfish. Two of 40 sturgeon (5%) and 3 of 22 catfish (13.6%) held in pens in the river died; all in the first day of holding. Whole fresh juvenile salmonids were best bait, followed by salted juvenile salmonids. Circle hooks caused injuries to all fish and were discontinued. The stainless steelhead/salmon hook was easy to remove and remained sharp.

4. Baited pots were set on 10 different occasions and yielded one northern squawfish.

5. Catch using bottom gill nets averaged 0.31 northern squawfish per hour: 122 northern squawfish were caught in 167 sets. Bottom gill nets had high incidential catch of species other than northern squawfish. About 60% of catch was suckers: only 14% was northern squawfish. Some mortality of fish caught with bottom gill nets was observed; five of nine steelhead died and many American shad appeared to be moribund.

6. Comparisons among gear show long-lines require the least investment and handling time and had the lowest incidential catch. Long-lines also caught the most northern squawfish. Potential problems with long-lines center around bait availability and conflicts with recreational gear. Alternative baits to fresh or salted juvenile salmonids are being tested. Times, areas and depths-of-set are being defined to minimize potential conflicts with recreational fishery.

REPORT A.

# Developing a Predation Index and Evaluating Ways to Reduce Juvenile Salmonid Losses to Predation in the Columbia River

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## ABSTRACT

We are reporting progress on the predator-prey study for the period August 28, 1988 to September 1, 1989. The purposes of this research are to evaluate the feasibility of an index for assessment of predation in various reservoirs throughout the Columbia River basin, to describe the relationships among predator-caused mortality of smolts and physical and biological variables: to examine the feasibility of developing bounty, commercial or recreational fisheries on northern squawfish ***(Ptychocheilus oregonensis);*** and to develop a plan to evaluate the efficacy of predator control fisheries. This parent project has three sub-components, presented separately in Reports B (Hanna 1990) and C (Mathews ***et*** al. 1990) of this volume, and the proposed work currently being conducted by Bledsoe (1989).

Literature searches on predator abundance indexing and factors regulating fish population dynamics have been conducted: selected references have been summarized, and compiled in a key-word bibliography format. The feasibility of various types of predator abundance indices is being assessed; existing data relevant to mark-recapture, catch per unit effort (CPUE), physical and chemical variables, and reservoir morphology have been compiled, reviewed, and summarized. In cases where sufficient data exist, preliminary implementation of predator abundance indices has been demonstrated. Field sampling in John Day Reservoir was conducted during May to August, 1989 -- to continue time series data bases on northern squawfish CPUE and growth, and to evaluate the possibility of year class strength determinations of northern squawfish and walleyes ***(Stizostedion vitreum vitreum)*** using restricted sampling. Development of plans has begun for fishery implementation and evaluation.

# INTRODUCTION

## Relationship to the Columbia River Basin Fish and Wildlife Program

Mortality **of** juvenile salmon and steelhead migrating downstream through the Columbia River system is a major concern of the Columbia Basin Fish and Wildlife Program (NPPC 1987). As outlined in the program, reservoir mortality is an area of emphasis for Bonneville Power Administration funding (NPPC 1987, Section 206(b) (1) (A)). Predation is an important component of mortality of juvenile salmonids migrating through the Columbia River System, and northern squawfish ***(Ptychocheilus* oregoneosis)** is an important predator (NPPC 1987, Section 401). There is general agreement that downstream passage and survival of juvenile salmonids are adversely affected by seasonally altered and low flows caused by the hydropower system -- thus increasing their exposure to predators (NPPC 1987, Section 301). The technical work group (TWG) on Reservoir Mortality/Water Budget Effectiveness (NPPC 1987, Section 206(b) (2)) has supported continued research and implementation of control measures to help alleviate the predation problem.

## Background

Development of the Columbia River basin hydroelectric system has created impoundments throughout the basin and enabled establishment and enhancement of resident fish that prey on juvenile salmonids as they migrate downriver to the ocean. The hydropower system has exacerbated the problem of predation-related mortality of juvenile salmonids in the Columbia River -- because impoundments have delayed migratory travel time, resulting in prolonged exposure (Raymond 1988). Recent studies (Poe and Rieman, editors 1988) have indicated that predation-caused mortality of juvenile salmonids is significant in John Day Reservoir. Northern squawfish was the most abundant predator (Beamesderfer and Rieman 1988a), had high consumption rates on juvenile salmonids (Vigg ***et*** al. 1988), and accounted for about 80% of the total losses in John Day Reservoir (Rieman ***et al. 1988).*** On a smaller scale, various studies (Sims ***et*** al. 1978; Uremovich et al. 1980) indicate that local concentrations of northern squawfish in tailraces and forebays of Columbia River basin dams can be great. These results are consistent with previous studies in the Columbia River basin that showed northern squawfish to be an important predator of juvenile salmonids (Zimmer 1953; USFWS 1957; Thompson 1959; Thompson and Morgan 1959). Poe ***et al.*** (1988) reviewed the literature describing various measures that have been used to control predator populations and identified those measures that had the greatest potential for success in the Columbia River. Modeling simulations of reservoir-wide potential predation in John Day Reservoir indicated that it is not necessary to eradicate northern squawfish in order to substantially reduce predation mortality: but that about 20% exploitation of the squawfish population by a sustained fishery could reduce juvenile salmonid losses to predation about 50% (Rieman and Beamesderfer 1988).

## Rationale

The significance and dynamics of predation are still unknown in other reservoirs in the Columbia River basin. Information is needed to estimate the relative importance of predation by northern squawfish throughout the mid and lower Columbia River and lower Snake River reservoirs, and determine if and where predation control measures should be applied. The cost, time, and uncertainty of absolute predation loss estimates as conducted in John Day Reservoir are prohibitive to conduct in each reservoir in the system. If a rapid assessment predation index is determined to be feasible, it will provide a cost-effective way to determine if the magnitude of fish predation in other Columbia River basin reservoirs is similar to that in John Day Reservoir. A plan is necessary for the orderly development of commercial, sport, or bounty fisheries on northern squawfish throughout the Columbia River Basin. Ongoing development of predator-prey modeling will help us to understand the dynamics of predation and predict possible consequences of predator removal. Development of a plan to evaluate the efficacy of predator control fisheries is essential for scientific management. This research project will provide the foundation for system-wide predation indexing and a comprehensive predator control program. The goal of this project is to reduce in-reservoir mortality of juvenile salmonids.

## Coordination

The Oregon Department of Fish and Wildlife (ODFW) and the U.S. Fish and Wildlife Service (USFWS) have been studying predation by northern squawfish on juvenile salmonids in the Columbia River since 1982 (BPA Projects 82-012 and 82-003); coordinated research continues for development of rapid assessment methods to index predation and simulation model development. ODFW has subcontracted with Oregon State University (Dr. Hanna) to evaluate the legal, institutional, socioeconomic, and biological feasibility of using bounty, commercial, and recreational fisheries to control northern squawfish populations. A harvesting technology component of the study is being conducted by University of Washington, Fisheries Research Institute (Dr. Mathews) -- to determine the combination of fishing methods, reservoir habitats, and time of year which is most efficient in removing northern squawfish from a Columbia River reservoir, with the least impact on other species. A third subcontract with University of Washington, Center for Quantitative Science (Dr. Bledsoe) involves the continued development of simulation modeling as a tool for predator control evaluation. These studies will provide information on what type of fishery and methodology would be most cost-effective and biologically efficient and effective in controlling northern squawfish populations.

## Objectives

The objectives of this study are: (1) to develop an index that can be used to estimate predation losses of smolts in various reservoirs throughout the Columbia River basin: (2) to describe the relationships among predator-caused mortality of smolts and physical and biological variables; (3) to examine the feasibility of developing bounty, commercial or recreational fisheries on northern squawfish, and (4) to develop a plan for the evaluation of the efficacy of predator control fisheries (upgraded from Task 3.4, BPA-ODFW contract). A detailed list of objectives and tasks, and a summary of progress to date on each are presented in Appendix A-l.

# METHODS

## Predation Index

We conducted a literature survey, and compiled a selected bibliography on various ways to index or estimate fish predator abundance (Appendix A-2). The literature on fish population assessment is very extensive and we only present representative references -- as a tool to facilitate ongoing work. The bibliography is divided by major topics which reflect the different types of stock assessment indices which may be feasible (Table A-l), and has key-words to facilitate finding specific aspects of interest. The current state of fish stock assessment methodology was recently summarized in an international symposium (Christie and Spangler, editors 1987). Conceptually, the predation index (P) will be the product of a predator abundance component (A) being developed here and a consumption index (C) being developed by the U.S. Fish and Wildlife Service (Poe and Nelson 1988):

$$P = A \cdot C$$

### Predation Questionnaire

At present little is known on the magnitude of system-wide predation: expert consultation (via questionnaires or workshops) is one method to obtain preliminary information (opinions or perceptions) when data are limited. For example, "The Delphi Technique" is a formalized iterative process of group opinion and feedback (Zuboy 1981). We asked the members of the Reservoir Mortality/Water Budget Effectiveness Technical Work Group (TWG) and the Fish Passage Advisory Council (FPAC) to provide expert consultation on the significance of system-wide predation and potential "predation hotspots" -- by filling out a questionnaire (Appendix A-3). Each committee member was also asked to identify other experts on system-wide juvenile salmonid mortality and predator abundance in order to obtain a representative cross-section of the fisheries community. The scoring of the predation index (PI) was from 0 to 25, based on the product of predator abundance (PA) and smolt abundance (SA) :

$$PI = PA \cdot SA,$$

Table A-l. Hierarchical arrangement of bibliography on population abundance estimates and indices.

I. Direct Measurement - Fish

A. Catch per Unit Effort (CPUE)

B. Creel Survey

C. Mark-recapture

D. Hydroacoustics - Total Ichthyomass

E. Total Biomass - Fish Standing Crop

F. Community Structure - Species Composition and Relative Abundance

G. Size structure - Species Length or Weight Composition

II. Indirect Measurement - Empirically Derived Indicators of Potential Fish Yield Based on Environmental Variables

A. Morphological

B. Physical and Chemical

(1) Nutrients and "Trophic Status”
(2) Oxygen
(3) Climate and Water Temperature

C. Biological

D. Derived Ratios

(1) Morpho Edaphic Index (MEI)

where PA and SA can each range from a minimum of 0 (none present) to a maximum of 5 (very abundant). The implicit assumption of using smolt abundance as a surrogate for predator consumption rate is that if smolts are present squawfish will eat them preferentially over alternate prey, and they will be consumed in proportion to their abundance; this assumption is probably realistic (see Discussion Section). If predator abundance (density) were homogeneous throughout the system, then smolt abundance (e.g., at the dams) could be used as an index of predation: and conversely, if smolt abundance were homogeneous throughout the system, then predator abundance alone would serve as a predation index. But since both PA and SA are heterogeneous through time and space, it is necessary to incorporate both components in an index.

### Hark-recapture population estimates

Reviews on methods are presented in Ricker (1975), Seber (1982), and White et *al.* (1982); an indexed bibliography on mark-recapture methods was compiled by Emery and Wydowski (1987). Available population estimates on reservoirs in the Columbia Basin were summarized. Methods used in John Day Reservoir were detailed by Beamesderfer and Rieman (1988a). The Overton (1965) estimator may be an appropriate method for evaluation of a predator control fishery since it allows for removals from the population.

### Catch per unit of effort (CPUE)

We reviewed and summarized literature on CPUE as an index of fish abundance. Pertinent existing data on CPUE and relative abundance of northern squawfish in various reservoirs *in* the Columbia Basin was tabulated.

Sampling in John Day Reservoir during 1983-1986 was stratified into four reservoir areas and sampled on a bi-weekly basis during April through June, 1984-1986 (Beamesderfer and Rieman 1988a). During each year, each time-area stratum was sampled with equal fishing effort using four gear types: gill nets, trap nets, electrofisher, and angling. Two types of 2.4 by 45.6-m monofilament gill nets were used: small mesh (3.2, 4.4, and 5.1-cm bar measure), and large mesh (6.4, and 7.6-cm). Gill nets were set on the bottom, perpendicular to shore. The Lake Erie style trap nets were either 3 or 5-m deep with 61-m leads of 3.2 or 3.8-cm bar mesh: these nets were also set on the bottom, with leads perpendicular to shore. Boat-mounted electroshockers were fished along shorelines and dam faces -- only at night. In addition, the catch of sport anglers was examined. Units of sampling effort were defined as one hour for gill nets, 24 hours for trap nets, 15 minutes current-on time for electrofishers, and one hour for anglers. Catch of each sampling method (numbers by species) was standardized per unit of effort. Fork length of target fish was measured to the nearest millimeter.

We are currently working on the development of a relative abundance (RA) estimate taking into account differential vulnerability by species, size group, and sampling gear (Vigg *et al.,* In Preparation).

$$RA = CPUE / v$$

Vulnerability (v) was estimated by the ratio of number of recaptured to total at-large marked fish (Lagler 1978; Beamesderfer and Rieman 1988a).

Habitat

Three methods were tested to relate the amount of available habitat to potential fish productivity: (1) extent of spatial habitat, (2) optimal thermal habitat, and (3) morphoedaphic index. Extent of spatial habitat can be expressed as reservoir length, area or volume. The morphometric characteristics of the mainstem and Snake Rivers were compiled and summarized from U.S. Army Corps of Engineers unpublished data and literature sources (Table A-2). An index of predator abundance was calculated, assuming that northern squawfish numbers in a given reservoir (Pi) were directly related to the amount of physical habitat (H), and the density throughout the Columbia River was equal to that in John Day Reservoir determined by Beamesderfer and Rieman (1988a):

$$P_i = N_{jd} \; H i \; / \; H_{jd}$$

where $N_{jd}$ is the number of northern squawfish in John Day Reservoir= 85,316, $H_{jd}$ is the amount of habitat in John Day Reservoir (length, area, or volume), and Hi is the amount of habitat in the given reservoir (length, area, or volume).

A second index was based on the fact that temperature has an overriding effect on fish physiology, growth, reproduction, and survival (Fry 1947) and is important in controlling all levels of ecological systems (Precht et *al. 1973).* This method is based on the assumption that a fish species abundance is directly related to the amount of optimum thermal habitat (Schlesinger and Regier 1983: Christie and Regier 1988). The optimum thermal range for northern squawfish (17-21 C) was approximated from available literature (Vigg et *al. 1988).* We compiled daily temperature data from six dams in the Columbia and Snake Rivers, 1978-1986 and computed daily means. Substantial variation occurred in the mean thermal regime of these reservoirs (Table A-3). The number of degree-days ($D_t$) in the optimum thermal range was calculated from the mean daily temperatures:

$$\text{if } T < T_u, \text{ and } T > Tl, \text{ then } D_t = T \; D$$

where T= environmental temperature (C), $T_u$= species-specific upper optimum thermal threshold (e.g., 21 C), $T_l$= species-specific lower optimum thermal threshold (e.g., 17 C), and D= the number of days within the optimum thermal range during April to September. The optimum thermal index (TI) was calculated as the product of the degree-days

Table A-2. Morphometric characteristics of mainstem Columbia and Snake River reservoirs (from U.S. Army Corps of Engineers unpublished data; Bell et ***al.*** 1976; Gray and Rondorf 1986; Mullan et ***al. 1986).***

| River Mile | Project | River or Reservoir Size | | | |
|---|---|---|---|---|---|
| | | Length (Miles) | Area (Acres) | Capacity (Acre-ft) | Mean Depth (ft) |
| Columbia: | | | | | |
| 0 | Estuary | 145.5 | | | |
| 145.5 | Bonneville | 46.2 | 20,400 | 565,000 | 27.1 |
| 191.7 | The Dalles | 23.9 | 10,500 | 332,500 | 31.7 |
| 215.6 | John Day | 76.4 | 50,000 | 2,370,OOO | 47.4 |
| 292 | McNary | 61.0 | 38,100 | 1,350,000 | 35.4 |
| 353 | Hanford Reach | 44.0 | | | |
| 397 | Priest Rapids | 18.0 | 7,000 | ***199,000*** | 28.4 |
| 415 | Wanapum | 38.0 | 13,800 | 587,000 | 42.5 |
| 453 | Rock Island | 21.0 | 2,500 | 113,700 | 45.5 |
| 474 | Rocky Reach | 41.8 | ***9,200*** | 430,000 | 46.1 |
| 515.8 | Wells | 29.2 | 10,700 | 300,000 | 28.0 |
| 545 | Chief Joseph | 52.0 | 7,800 | 516,000 | 66.2 |
| 597 | Grand Coulee | 150.0 | 80,000 | 9,562,000 | 119.5 |
| 747 | | | | | |
| | Total: | 747.0 | 250,000 | 16,325,200 | 65.3 |
| Snake: | | | | | |
| 9.7 | Ice Harbor | 31.9 | 8,330 | 407,000 | 48.9 |
| 41.6 | Lower Monumental | 28.7 | 6,740 | 377,000 | 55.9 |
| 70.3 | Little Goose | 37.2 | 9,920 | 365,000 | 36.8 |
| 107.5 | Lower Granite | 53.0 | 8,900 | 484,000 | 54.4 |
| 160.5 | | | | | |
| | Total: | 150.8 | 33,890 | 1,633,000 | 48.2 |
| Overall Total: (not including estuary & Hanford) | | 897.8 | 283,890 | 17,958,200 | 63.3 |

Table A-3. Comparison of thermal habitat of various mainstem Columbia and lower Snake river reservoirs, during July to September, 1978-1986.

| Reservoir Area (Dam Tailrace) | Thermal Range (C) | Days in Thermal Range (Percent of total) |
|---|---|---|
| McNary Dam | 0-5 | 0 |
| | 5-10 | 15.3 |
| | 10-15 | 29.0 |
| | 15-20 | 36.6 |
| | 20-25 | 22.4 |
| Ice Harbor Dam | 0-5 | 0 |
| | 5-10 | 12.0 |
| | 10-15 | 34.4 |
| | 15-20 | 25.7 |
| | 20-25 | 28.4 |
| Lower Monumental Dam | 0-5 | 0 |
| | 5-10 | 14.2 |
| | 10-15 | 33.3 |
| | 15-20 | 23.5 |
| | 20-25 | 29.5 |
| Little Goose Dam | 0-5 | 0 |
| | 5-10 | 12.6 |
| | 10-15 | 35.0 |
| | 15-20 | 25.7 |
| | 20-25 | 30.1 |
| Lower Granite Dam | 0-5 | *0* |
| | 5-10 | 11.5 |
| | 10-15 | 35.0 |
| | 15-20 | 24.0 |
| | 20-25 | 30.6 |
| Dworshak Dam | 0-5 | 11.5 |
| | 5-10 | 52.5 |
| | 10-15 | 30.1 |
| | 15-20 | 0 |
| | 20-25 | 0 |

within the optimum thermal range (Dt) and the volume (V) of the reservoir:

$$TI = D_t V$$

Thus we are also assuming that temperature is homogeneous within the reservoir during April to September.

The third index of potential fish productivity we tested was the Morphoedaphic Index, ME1 (Ryder 1965):

$$MEI = TDS / Dm$$

where TDS= total dissolved solids (ppm), and $D_m$= mean depth (feet). This index assumes fish productivity is directly related to the salinity of the water and inversely related to the depth of the reservoir. Since we could not find any TDS data for reservoirs in the Columbia River System, we used conductivity as a surrogate measure: conductivity is linearly related to TDS. Conductivity measurements from below Bonneville Dam were obtained from Clark and Snyder (1970); data from Chief Joseph and F.D. Roosevelt reservoirs were derived from Erickson et *al.* (1977) and Stober et *al.* (1981). respectively: and data from Snake River reservoirs were obtained from Funk et al. (1985).

In addition, a selected key-word bibliography was compiled on various habitat index methods and models (Appendix A-4). The Habitat Evaluation Procedure (HEP) is an example of more sophisticated (multivariate) habitat modeling approach (USFWS 1980a, 1980b). Habitat assessments using HEP are based on Habitat Units (HU) which are the product of the Habitat Suitability Index (HSI) and the area of available habitat (A) :

$$HU = HSI \quad A .$$

The HSI is defined as a numerical index from 0 (unsuitable) to 1.0 (optimum) that represents the capacity of a given habitat to support a given fish species (USFWS 1981). Methods and guidelines have been documented for implementing riverine and lacustrine HSI models (Terrell *et al.* 1982, Terre11 1984).

## Relations between predation and environmental variables

### Modeling ecological relations

We assisted U.S. Fish and Wildlife Service (Project 82-003) by providing input to Dr. James Petersen regarding predation dynamics, serving on the Steering Committee for the Predator-Prey Modeling Workshop, and participating in the workshop held at Friday Harbor, Washington on May 16-19, 1988. We helped refine the predation simulation model by assisting Dr. L.J. Bledsoe with the Columbia River Ecology Model (CREM), and preparing a detailed statement of work for modifying CREM and using simulation modeling as a tool to evaluate predator control. We completed a manuscript on the relation between temperature and maximum consumption rate of northern squawfish (Vigg and Burley 1989) -- which in conjunction with the functional response relation (Vigg 1988) quantifies an updated consumption sub-model for incorporation in CREM.

### Year class strength

We reviewed literature on factors regulating year class strength, and potential compensatory mechanisms among predator populations (Appendix A-51. Of the major piscivores in the mainstem Columbia River: extensive literature is available on walleyes *(Stizostedioo vitreum vi treum)* ; substantial information exists on smallmouth bass *(Micropterus dolomieui)* and channel catfish *(Ictalurus punctatus);* but very little information is available on factors regulating the population dynamics of northern squawfish.

## Field Sampling

Northern squawfish and walleyes were collected from the Columbia River, John Day Reservoir during May-August 1989. Five sample sites were used: McNary Dam Boat Restricted Zone, McNary Dam Tailrace, Irrigon, Arlington, and the John Day Forebay (Figure A-l).

Fish were collected primarily with stationary bottom gill nets 45.6 m long, 2.4 m deep with six panels 7.6 m long. Each half of a net consisted of three monofilament nylon mesh panels (3.2 cm, 4.4 cm, and 5.1 cm bar mesh). This gear was chosen to allow direct comparison of data collected this year with data collected during 1982-1988 (Nigro *et al. 1985).* Fish were also collected from the McNary Dam Tailrace using hook and line angling.

### Study Site

John Day Reservoir is the third mainstem impoundment upstream from the mouth of the Columbia River. It is bounded by John Day Dam at river km (rkm) 347 and McNary Dam at rkm 470; i.e., it is 123 km in length. At its mean elevation of 89 m above mean sea level, John Day Reservoir has a mean width of 1.8 km, a maximum width of 4.0 km, a mean depth of 8.0 m, a maximum depth of 44.2 m, a surface area of about 210 $km^2$ , and a volume of about 2.97 . $10^{15}$ $m^3$. Based on river velocity, Hjort *et al.* (1981) separated John Day Reservoir into three zones: tailrace, rkm 462-470; transitional, rkm 405-462; and, forebay, rkm 347-405. The upper reservoir is generally lenthic in the main channel with numerous islands and shallow embayments in the backwaters: whereas the remainder of the reservoir is lotic in character -- relatively deep, with steep shorelines and a small littoral zone. Water temperature extremes range from 0 to 27 C each year, with minima generally occurring in February and maxima in August -- persistent vertical thermal stratification usually does not occur.

### Species and Size composition

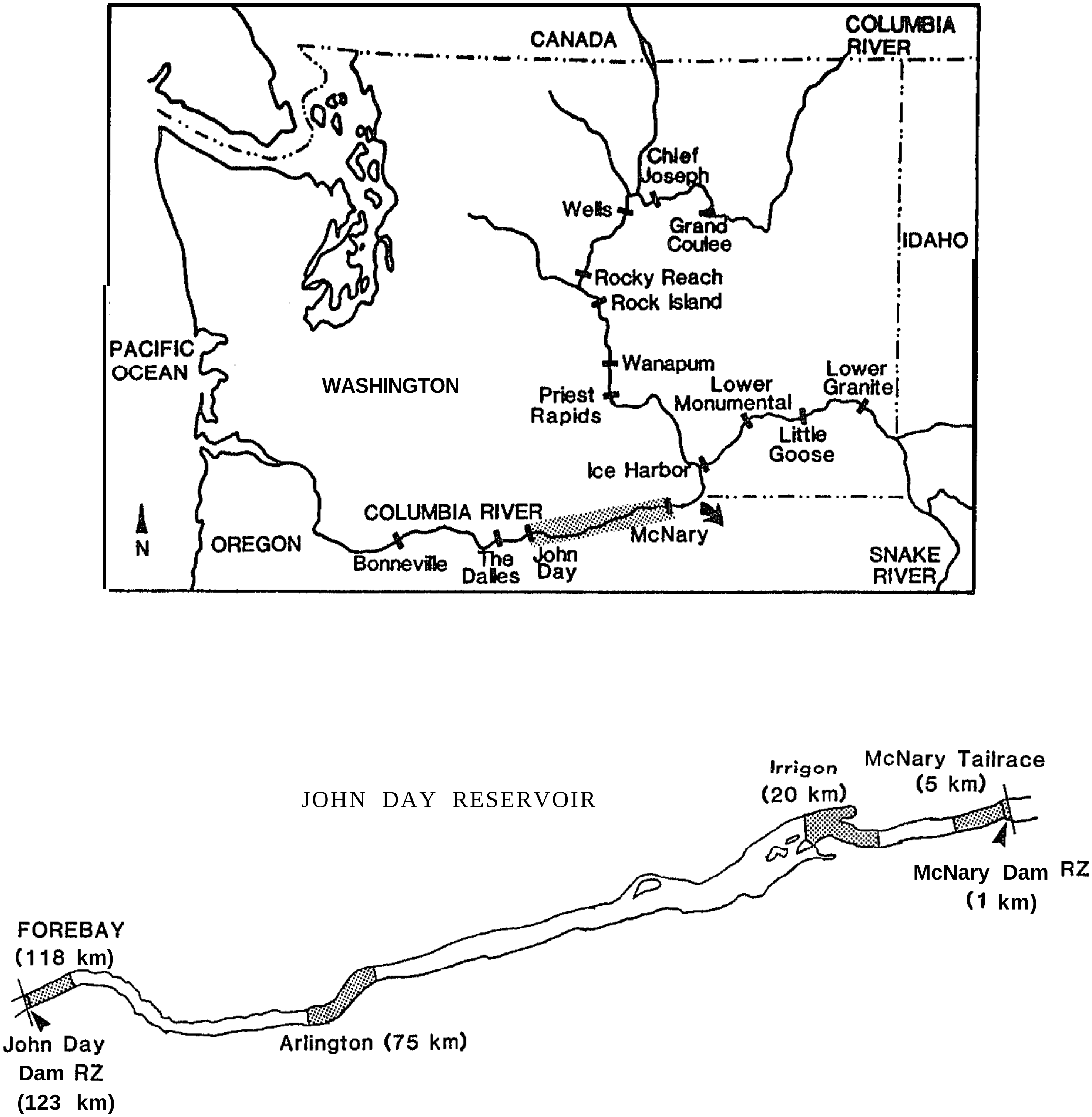


Figure A-l. Map of John Day Reservoir, showing sampling transects.

All fish species captured were enumerated. Fork length (mm), weight (g), sex and scale samples were taken from individual northern squawfish collected in the bottom gill nets. Walleyes in good physical condition were measured for length and weight, marked with Floy Spaghetti Tags, and released without sex information gathered. Length data were collected from the northern squawfish caught hook and line angling from McNary Dam.

## Catch per unit effort (CPUE)

Catch per unit effort analyses were made for northern squawfish and walleye using bottom gill net sets of l-3 h in duration (n= 159).

$$CPUE = C / f$$

where C is the number of fish, and f is the effort (number of sets times hours set).

## Age determinations

Age determination procedures from scale samples collected during the 1989 field sampling were similar to those used on the John Day Reservoir during 1982-1986 (Beamesderfer et al. 1987).

Scales (10-20) from northern squawfish were collected on the left side of the fish from the region posterior to the dorsal fin and above the lateral line. Scales (10-20) from walleyes were collected on the left side of the fish from the region below the lateral line, near the posterior end of the pectoral fin when the fin is pressed to the body. All scale samples were analyzed for age determinations.

Scales were prepared and mounted using the following procedures. All scales collected from an individual fish were placed in a petri dish with water and were examined under a dissection microscope. Four to six good scales were chosen for mounting. Criteria for selection of good scales were: (1) scale not irregular shaped (e.g., very large, small, oblong); (2) scales not cracked or distorted: (3) scales not regenerated (missing circuli particularly by the focus). Each scale was cleaned on both sides using a Buttler Proxabrush until (using light pressure to avoid scratching the scale) all skin, mucus and debris was removed. The scales were then placed on scale cards for pressing. Scale cards were placed on acetate sheets for making impressions. The impressions were made using a scale press at a temperature of 220-240 F, for 3.0 min, at 6000 psi.

Scale aging methods and terminology were patterned after Jerald (1983) and Bagenal and Tesch (1978). Age determinations were made by placing the scale impression into the NCR Microfish projector (43X magnification) and directly counting annuli. A second scale was used to verify the age.

The features used to identify an **annulus** were: (1) "cutting over", when one or two circuli appear to cut across several others (usually more visible at the dorso-lateral and ventro-lateral parts of the scale); (2) the circuli become markedly discontinuous; (3) a zone of closely-spaces circuli followed by a zone of widely-spaced circuli; the **annulus** is considered the outer boarder of the closely-spaced circuli.

The features used to identify checks were: (1) a ring with closely spaced rows of circuli or "cutting over" that is discontinuous around the edge of the scale: (2) a ring with fewer rows of circuli than are present in obvious **annuli;** (3) circuli of the wrong type (broad rather than narrow as in true **annuli).** The features used to identify "split annulus" were: (1) unusual spacing of rings, especially in a paired pattern: (2) observation of fast growth on the edge during the winter months;

Precision of age determinations is in progress and will be completed for the Final Report. The methods we are using for estimating the precision of age determinations is patterned after those of Beamish and Fournier (19811, and Chang (1982). The reader ages the sample of scales three independent times each without any knowledge of the fish length. This will allow us to determine the average percent error, the coefficient of variation and an index of precision for the reader.

Year class strength

Two general spreadsheets were developed to test the various methods for estimating relative year class strengths using basic catch data typically collected (length, weight, sex, age, and catch per unit effort). One worksheet (YCSSQFl.CAL) used a fish species that is recruited to the gear at age five and lives to be fourteen, and the other (YCSWALl.CAL) used a fish species that is recruited to the gear at age two and lives to be seven. The spreadsheets were constructed so that the basic input variables could be changed and these changes would be incorporated in all calculations throughout the spreadsheet.

The methods analyzing year-class strengths compared were: Iiile (1941); El-Zarka (1959); Extrapolation ***of*** Cohort Regression from Gulland (1983); the ***Recruitment Method*** modified from Gulland (1983), and the ***Rieman Residual Method*** from Rieman and Beamesderfer (1988). We are in the process of systematically varying the input variables and conducting sensitivity analyses using simple correlation analysis. The input variables are: population size (numbers), sample size, number of capture years, age groups (numbers and ages), and age specific mortality estimates.

Predator Control Fishery Development & Evaluation Plan

We have developed preliminary plans for: ***Predation Indexing --*** to assess the system-wide magnitude of predation: a ***Test Fishery --***to evaluate relative effectiveness of commercial-bounty, sport-bounty, and dam angling fisheries on a small scale in 1990; and an ***Evaluation -- to*** assess the efficacy of predator control fisheries. In the development of these plans, we have worked very closely with BPA (Stephen Smith and William Maslen) and fishery and Tribal Agencies through the Fisheries Passage Advisory Committee, and the Reservoir Mortality / Water Budget Effectiveness Technical Work Group (RM/WBE TWG; Fred Olney, Chairman). The ODFW Columbia River Coordinator's Office: i.e., Frank Young and Ron Boyce have served as liaison between our project and various agencies, Tribes, and committees. We have also consulted with our project cooperators: i.e., Thomas Poe, Project 82-003 (USFWS) and our three subcontractors (Susan Hanna, OSU; S.B. Mathews, UW-FRI; L.J. (Sam) Bledsoe, UW-CQS) . We have made presentations for peer review at the ODFW Biennial Research Review, for BPA officials at BPA Headquarters, for RM/WBE TWG members on several occasions, and at the 16th Inter-agency Research Coordination Conference.

# RESULTS

## Predation Index

### Predation Questionnaire

There is general consensus among agencies, Tribes and the Northwest Power Planning Council that predation by northern squawfish is an important source of mortality on juvenile salmonids (Ron Boyce, ODFW, Personal Correspondence: NPPC 1987); however it is not well documented what the relative magnitude of predation is in various reaches and reservoirs throughout the Columbia River basin. Juvenile salmonid abundance is generally better quantified than northern squawfish abundance at most projects, since smolt passage at mainstem dams has been indexed in recent years (e.g., FPC 1989). If predator abundance were homogeneous, then smolt passage alone (Figure A-2) would provide an index of predation -- since northern squawfish preferentially consume smolts.

Preliminary results (primary contacts) of a "Predation Questionnaire" submitted to a cross-section of fishery biologists working on reservoir mortality and related problems indicate there is a general perception that hydroelectric projects in the lower Columbia River have the greatest predation problem (Table A-4, Appendix A-3). A prime consideration pertaining to the magnitude of predation at Bonneville Powerhouse 2 (forebay and tailrace) is if it is operational (Margaret Filardo, FPC, Personal Correspondence); and if so, how the flow is managed through the turbines versus spill. Other projects which were listed as ***"predation hotspots"*** were Priest Rapids, Wells, Ice Harbor, and Lower Granite. Because of planned smolt bypass work at The Dalles Tailrace, it was also considered as a high priority area by some RM/WBE TWG members. Many contacts indicated that there was insufficient information to make "scientific" judgements, and that their responses were only guesses, and in some cases contacts preferred not to respond. Based on percent response by area (in parentheses), there appeared to be

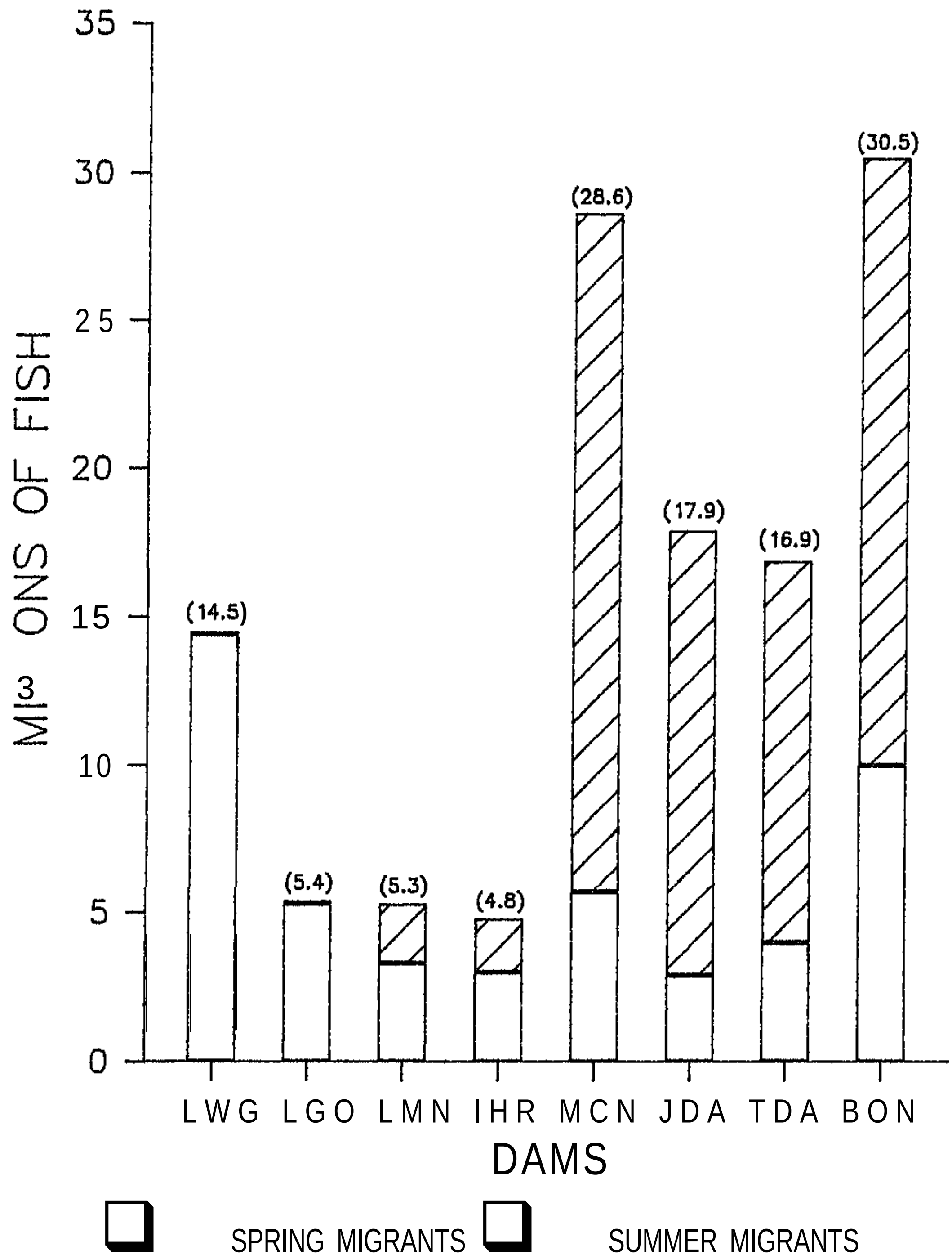


Figure A-2. Estimated number of salmonid smolts arriving at eight lower Snake and lower Columbia River Dams, 1988 (From Chris Ross, National Marine Fisheries Service).

Table A-4. Top 14 ranked areas by mean predation index, and predation "hotspots" based on expert opinion of the Reservoir Mortality/Water Budget Effectiveness Technical Work Group (TWG) and secondary contacts recommended by the TWG; see Appendix A-3 for detailed tabulation of responses.

| Rank | Dam, Reservoir Area | Response n= 26 (percent) | Predation Index (mean) | Identified as Hotspot (number) |
|---|---|---|---|---|
| 1. | Bonneville 1, Tailrace | 65.4 | 22.8 | 8 |
| 2. | Bonneville 1, Forebay | 73.1 | 22.6 | 10 |
| 3. | McNary Dam, Tailrace | 73.1 | 18.8 | 9 |
| 4. | McNary Dam, Forebay | 65.4 | 18.5 | 4 |
| 5. | John Day Dam, Forebay | 76.9 | 17.9 | 4 |
| 6. | Bonneville 2, Tailrace | 65.4 | 17.5 | 4 |
| 7. | John Day Dam, Tailrace | 65.4 | 17.2 | 2 |
| 8. | Bonneville 2, Forebay | 61.5 | 16.9 | 2 |
| 9. | The Dalles Dam, Tailrace | 50.0 | 15.9 | 3 |
| 10. | The Dalles Dam, Forebay | 50.0 | 15.2 | 3 |
| 11. | John Day, Reservoir | 73.1 | 14.6 | 4 |
| 12. | Bonneville, Reservoir | 53.8 | 14.0 | 2 |
| 13. | McNary, Reservoir | 61.5 | 13.8 | 2 |
| 14. | Lower Granite, Forebay | 50.0 | 13.5 | 1 |

more uncertainty in the Estuary (49%), mid-Columbia (43%) and Snake River (46%) than in the lower Columbia River (62%).

## Hark-recapture population estimates

Absolute population estimates of northern squawfish in Columbia and Snake river reservoirs are limited (Table A-5). Depending on possible violations of assumptions, the population estimate in John Day Reservoir could vary an order of magnitude (50,000 to 500,000). The population estimate of northern squawfish in John Day Reservoir during 1983-1986 (about 85,000) corresponds to a density of about 4.4 per hectare which is the lowest density reported in the literature for this species (Beamesderfer and Rieman 1988a). For comparison, in Cascade Reservoir, Idaho 200,000 northern squawfish were removed in one year and 400,000 in five years (Lindland 1973) -- this translates to a density of about 18.5 to 37 squawfish per hectare. In the Snake River during 1976, Sims et al. (1977) captured over 22,000 northern squawfish using Merwin Traps in the upper end of Lower Monumental Pool -- and made a population estimate of 133,000 (compared to their estimate of 120,000 during 1975). Sims *et* al. (1978) estimated 45,000 northern squawfish in the tailrace of Lower Granite Dam and 75,000 in the tailrace of Little Goose Dam. LeMeir and Mathews (1962) reported a migratory population of about 40,000 northern squawfish passing through The Dalles tailrace. In 1981, Uremovich et al. (1980) estimated about 11,000 northern squawfish inhabited the forebay of Bonneville Powerhouse Number 1. Recently National Marine Fisheries Service made a preliminary population estimate of about 58,000 northern squawfish in the Bonneville Forebay (John Williams, NMFS, Personal Correspondence). The number of Sacramento squawfish (*Ptychocheilus grandis*) passing Red Bluff Diversion Dam, Sacramento River, California during 1982-1987 was estimated at about 12,000 to 40,000 fish each year, with an "effective" population of 160,000 to 515,000 squawfish congregated below the dam (Vondracek et al. 1989).

## Catch per unit of effort (CPUE)

A selected key-word bibliography of CPUE as an index of abundance is contained in Appendix A-2: a summary of important aspects (e.g., specific indices, selectivity and vulnerability) is presented in Table A-6. Catch per unit of effort (CPUE) is commonly used as an index of fish abundance in four general ways. First, to estimate the relative proportions of different species within a community, i.e., relative abundance. Second, to monitor the changes in a given stock of fish over time, i.e., temporal dynamics. Third, to evaluate the differences in numbers of a given stock within a certain ecosystem or geographical area, i.e., area1 distribution. Fourth, to determine the relative proportions of the age classes of a given fish stock, e.g., for catch-curve mortality estimates, and cohort analysis.

In the basic catch equation (Ricker 1940; Gulland 1964; Paloheimo and Dickie 1964), catch ($C$) is expressed as a linear function of catchability ($q$), fishing effort ($f$), and fish abundance ($N$):

Table A-5. Mark-recapture fish population estimates in various Columbia River Reservoirs.

| Reservoir/ Location | Date | Species (Length) | Population Size (Numbers) | Variability Estimate (95% CI) | Reference |
|---|---|---|---|---|---|
| Upper half Lower Monumental | 1975 -76 | N. squawfish | 120,000 (1975) 133,000 (1976) | -- | Sims et al. (1977) |
| Little Goose Tailrace | 1977 | N. squawfish | 75,000 | -- | Sims et al. (1978) |
| Lower Granite Tailrace | 1977 | N. squawfish | 45,000 | -- | Sims *et al.* *(1978)* |
| John Day Reservoir | 1983 -86 | N. squawfish 0 250 mm) | 85,316 | 65,696 to 109,204 | Beamesderfer & Rieman (1988a) |
| | | | 52,898 to 490,540[a] | | |
| | | S.M. Bass (> 200 mm) | 34,954 | 25,167 to 44,741 | |
| | | Walleyes 0 250 mm) | 15,168 | 6,067 to 17,747 | |
| The Dalles Tailrace cul-de-sac | 1962 | N. Squawfish | 39,705[b] | -- | LeMier & Mathews (1962) |
| Bonneville Powerhouse Number 1 Forebay | 1981 | N. squawfisb | 358 to 18,174[c] | 262 to 28,679 | Uremovich *et al.* *(1980)* |
| | | | 11,569[d] | | |
| | 1989 | N. Squawfish | 54,480 to 61,828[e] | 30,099 to 100,960 | John Williams, NMFS. Personal Correspondence[f] |

[a] Varies by assumption violation
[b] Migratory segment of population
[c] Varies by week
[d] Using Overton (1965) method
[e] Varies by estimation method
[f] Memo from Benjamin Sanford to John Williams, dated Sept. 12, 1989

Table A-6. Summary of literature related to catch per unit effort (CPUE) as a measure of fish population abundance.

| Topic/ aspect | Species/ gear[a] | Hypothesis or question | Conclusion / Reference (Appendix A-2) |
|---|---|---|---|
| Abundance (N): | | | |
| Index | marine/ AN & CO | Is CPUE an index of abundance? | Based on an ordinary least squares and errors-in-variables models, CPUE was directly proportional to single species, but not aggregate species population size (Richards and Schnute 1986). |
| | marine/ AN & CO | What measure of C/f is correlated with abundance? | The square root of relative frequency of zero C/f is less biased than mean C/f (Bannerot and Austin 1983). |
| Relative Abundance | Northern squawfish, trout, char /GN | Can gill nets be used to measure changes in abundance of fish? | Gill net CPUE can be used to measure temporal changes in northern squawfish abundance and size structure (Foerster and Ricker 1938, 1941). |
| | Skipjack tuna/ AN | What sources are responsible for fluctuations in landings? | Variations in the availability and vulnerability, and possibly fluctuations in year classes contributed to fluctuations in landings of skipjack tuna (Uchida 1967). |
| Absolute Abundance | Herring/ PS, HA | Can purse seine catches and hydroacoustics be used for absolute fish density estimates? | Both measurement methods have the potential for large bias: they had a 3 times difference in absolute density estimates. Time series measurements of relative fish abundance with standard techniques are more reliable than absolute estimates (Mulligan et al. 1987). |
| Catchability (q): | | | |
| Constant | marine/ TR | What causes variations in catchability? | Many factors can affect q: fishing power; vulnerability to the gear: seasonal and spatial patterns of distribution: stock abundance (Gulland 1964; Garrod 1964). |

Table A-6. continued.

| Topic/ aspect | Species/ gear[a] | Hypothesis or question | Conclusion/ Reference (Appendix A-2) |
|---|---|---|---|
| Constant | Salmon/ AN | Is catchability independent of population size? | There is an inverse (type II) relation between q and N (Peterman and Steer 1981). |
| Constant | Herring/ PS, GN | Is catchability independant of stock area? | There is an inverse relation between q and stock area (Winters and Wheeler 1985). |
| Commercial Fishery statistics: | | | |
| Stochastic C/f model | Halibut/ SL | Is C/f an accurate estimator of fish abundance? | Abundance (N) of a heavily exploited fish population can be estimated from catch and effort data assuming a competing-risk model of adult deaths, similar to the hazard-regression model of Cox (1972); N, error bounds, and predictions of subsequent catches are derived from maximum-likelihood estimates of the parameters of the model (Dupont 1983). |
| Population Model | Herring/ PS. GN | Can commercial catch rate data be used to calibrate population models? | Commercial fishery C/f data are likely to be biased and should be used with caution: instead, emphasis should be placed on research vessel survey data collected in a standard manner over the distributional area of a stock (Winters and Wheeler 1985). |
| **Mortality:** | | | |
| ln(CPUE) vs effort and age | Lake trout/ AN | Can ln(CPUE) be related to size of the cohort and mortality? | These relations can give estimates of natural mortality rate, catchability coefficient, and size of the cohort (Paloheimo 1980). |

Table A-6. continued.

| Topic/ aspect | Species/ gear[a] | Hypothesis or question | Conclusion/ Reference (Appendix A-2) |
|---|---|---|---|
| Sampling design: | | | |
| Random sampling | 15 species/ *ES* | Is fixed sampling biased? | Based on mean and variances of total weight and percent composition fixed sites are acceptable (King et al. 1981). |
| Selectivity: | | | |
| Review | Various/ GN, TR, HO, PO, SE | What is selectivity ,what causes it, and how can it be measured? | Selectivity is any factor that causes the size composition of the catch to differ from that of the population. It is caused by (a) differences in area or time fished, (b) differences in probability of specific size fish encountering gear, or (c) difference in probability of specific size fish escaping. It is measured by relating fish size to catchability (q) (Pope *et al. 1975).* |

[a] ES= electrafishing
AN= hook and line angling
CO= visual fish counts
GN= gill net
SL= set line
HO= hook
TR= trawl
PS= purse seine
SE= seine
PO= pot
HA= hydroacoustics

$$C = q \cdot f \cdot N, \text{ or}$$

$$C/f = q \cdot N$$

Thus, this model assumes that C/f (= CPUE) is linearly related to N, and that a percent change in C/f is equal to a percent change in N. It is generally realized, however, that the assumption of direct proportionality is often invalid under natural conditions (Richards and Schnute 1986). Catchability is not always constant, but may vary as a function several factors: fish species (e.g., behavior and morphology); stock size (age) distribution: fishing gear characteristics: and, environmental conditions.

Catch per unit effort (CPUE) of northern squawfish in John Day Reservoir during 1984-1986 varied by sampling gear, year, month, and reservoir location (Table A-7). This variability shows the need to stratify sampling by both time and area in order to obtain a representative mean seasonal CPUE for a given reservoir. For example, the CPUE of electroshockers in June 1984 was over 40 times greater in McNary Dam Tailrace boat restricted zone (BRZ) than in the remainder of the reservoir: and the timing of the maximum catches in the BRZ and their ratio to the catches in the John Day pool varied on an annual basis. Another example of spatio-temporal interactions is order of magnitude differences between CPUE of electroshockers in June 1984 at John Day Forebay, July 1985 at Arlington, and August 1986 at Irrigon -- compared to concurrent catches at the other locations during the same year. Thus, gross errors could result by making inferences from a CPUE sampling design which was too restricted spatially or temporally.

Beamesderfer and Rieman (1988b) documented the length-frequency distributions of catches by sampling gears and estimated size-specific vulnerability of northern squawfish from the ratio of recaptures to number of tagged fish at-large. We are currently investigating the possibility of using this method to adjust size-specific CPUE by sampling gear type for catchability (q) , since:

$$N = CPUE / q$$

This may be a way to adjust a CPUE index for variable catchability (Table A-8).

Relative abundance of northern squawfish compared to other species in the community has been assessed in various reservoirs in the Columbia Basin: John Day, Hjort et al. (1981); McNary, Nelson (1981); Chief Joseph, Laumeyer (1972) and Erickson *et* al. (1977); Wells, McGee (1979); mid-Columbia, Dell et al. (1975); Hanford Reach, Gray and Dauble (1977); F.D. Roosevelt, Beckman et al. (1985); and lower Snake, Bennett et ***al.* *(1983, 1988).*** The data from these studies indicate that northern squawfish comprises a significant component (3-34%) of the fish community throughout the mid-Columbia and lower Snake rivers (Mullan et al. 1986; Table A-9). John Day Reservoir had the lowest percent composition of the areas surveyed. During 1955-56 in Bonneville Reservoir, northern squawfish comprised about 27% of the catches of

Table A-7. Catch per unit effort (CPUE) of northern squawfish (> 250 mm) in John Day Reservoir during 1984-1986, by sampling gear and location.

| Gear (effort) | Year/ Location | CPUE by Month | | | | | Mean |
|---|---|---|---|---|---|---|---|
| | | April | May | June | July | August | |
| Electroshock (0.25 hr) | 1984: | | | | | | |
| | J.D. Forebay | 0.71 | 0.88 | 0.06 | 0.78 | 0.31 | 0.55 |
| | Arlington | 0.50 | 0.75 | 0.60 | 0.46 | 0.35 | 0.53 |
| | Irrigon | 0.38 | 0.52 | 0.51 | 0.19 | 0.19 | 0.36 |
| | McNary | 0.24 | 0.53 | 1.15 | 1.22 | 0.25 | 0.68 |
| | McNary BRZ | 5.83 | 14.00 | 25.67 | 5.38 | 6.31 | 11.44 |
| | Mean: | 1.53 | 3.34 | 5.60 | 1.61 | 1.48 | 2.71 |
| | 1985: | | | | | | |
| | J.D. Forebay | 0.29 | 0.31 | 0.41 | 0.36 | 0.67 | 0.41 |
| | Arlington | 0.23 | 0.13 | 0.16 | 0.06 | 0.29 | 0.17 |
| | Irrigon | 0.42 | 0.33 | 0.20 | 0.42 | 0.12 | 0.30 |
| | McNary | 0.63 | 1.33 | 1.06 | 0.30 | 0.14 | 0.70 |
| | McNary BRZ | 6.37 | 12.63 | 9.40 | 12.08 | 13.18 | 10.73 |
| | Mean: | 1.59 | 2.94 | 2.25 | 2.64 | 2.88 | 2.46 |
| | 1986: | | | | | | |
| | J.D. Forebay | 0.34 | 0.12 | 0.22 | 0.73 | 0.27 | 0.34 |
| | Arlington | 0.24 | 0.21 | 0.14 | 0.40 | 0.42 | 0.28 |
| | Irrigon | 0.20 | 0.70 | 0.81 | 0.11 | 0.04 | 0.37 |
| | McNary | 0.33 | 0.90 | 1.02 | 0.18 | 0.30 | 0.55 |
| | McNary BRZ | 7.17 | 5.14 | 9.09 | 6.79 | 9.90 | 7.62 |
| | Mean : | 1.66 | 1.42 | 2.26 | 1.64 | 2.19 | 1.83 |
| Gill net (1.0 hr) | 1984: | | | | | | |
| | J.D. Forebay | 1.80 | 2.75 | 2.71 | 1.94 | 1.87 | 2.21 |
| | Arlington | 1.41 | 0.93 | 0.84 | 1.06 | 0.43 | 0.93 |
| | Irrigon | 0.52 | 1.01 | 2.12 | 1.18 | 1.70 | 1.31 |
| | McNary | 1.55 | 2.56 | 5.84 | 2.42 | 1.12 | 2.70 |
| | McNary BRZ | -- | -- | -- | -- | 1.00 | 1.00 |
| | Mean: | 1.32 | 1.81 | 2.88 | 1.65 | 1.22 | 1.75 |

Table A-7. continued.

| Gear (effort) | Year/ Location | CPUE by Month | | | | | Mean |
|---|---|---|---|---|---|---|---|
| | | April | May | June | July | August | |
| Gill net | 1985: | | | | | | |
| | J.D. Forebay | 1.80 | 1.65 | 2.03 | 1.91 | 1.36 | 1.75 |
| | Arlington | 1.72 | 1.62 | 0.88 | 1.00 | 1.14 | 1.27 |
| | Irrigon | 1.24 | 2.50 | 2.24 | 1.19 | 0.65 | 1.56 |
| | McNary | 2.50 | 2.81 | 3.60 | 1.32 | 0.69 | 2.18 |
| | McNary BRZ | 0.50 | -- | -- | -- | 2.75 | 1.62 |
| | Mean: | 1.55 | 2.14 | 2.19 | 1.35 | 1.32 | 1.69 |
| | 1986: | | | | | | |
| | J.D. Forebay | 1.67 | 1.75 | 1.05 | 1.91 | 0.84 | 1.44 |
| | Arlington | 1.96 | 1.12 | 0.70 | 0.98 | 0.86 | 1.13 |
| | Irrigon | 0.95 | 1.70 | 2.04 | 0.70 | 0.76 | 1.23 |
| | McNary | 0.85 | 1.59 | 1.78 | 0.80 | 0.28 | 1.06 |
| | McNary BRZ | -- | 4.00 | -- | 3.00 | 4.46 | 3.82 |
| | Mean: | 1.36 | 2.03 | 1.40 | 1.48 | 1.44 | 1.55 |
| Trap net (24.0 hr) | 1984: | | | | | | |
| | J.D. Forebay | 0.37 | 2.12 | 2.74 | 6.68 | 1.05 | 2.59 |
| | Arlington | 2.64 | 3.78 | 3.97 | 3.20 | 1.99 | 3.11 |
| | Irrigon | 1.60 | 0.77 | 0.47 | 1.21 | 2.86 | 1.38 |
| | McNary | 0.59 | 3.44 | 2.66 | 0.66 | 1.65 | 1.80 |
| | McNary BRZ | -- | -- | -- | -- | -- | -- |
| | Mean: | 1.30 | 2.53 | 2.46 | 2.94 | 1.89 | 2.22 |
| | 1985: | | | | | | |
| | J.D. Forebay | 2.57 | 3.30 | 2.82 | 0.51 | 0.25 | 1.89 |
| | Arlington | 0.34 | 0.94 | 0.84 | 0.91 | 0.52 | 0.71 |
| | Irrigon | 1.71 | 1.74 | 1.63 | 2.61 | 0.54 | 1.65 |
| | McNary | 0.97 | 1.73 | 1.20 | 0.40 | 0.06 | 0.87 |
| | McNary BRZ | -- | -- | -- | -- | -- | -- |
| | Mean: | 1.40 | 1.93 | 1.62 | 1.11 | 0.34 | 1.28 |
| | 1986: | | | | | | |
| | J.D. Forebay | 2.03 | 2.04 | 4.60 | 1.12 | 1.78 | 2.32 |
| | Arlington | 0.67 | 1.54 | 2.86 | 0.71 | 0.52 | 1.26 |
| | Irrigon | 0.66 | 0.20 | 1.24 | 0.58 | 0.75 | 0.69 |
| | McNary | 0.96 | 1.02 | 0.73 | 0.13 | 0.18 | 0.60 |
| | McNary BRZ | -- | -- | -- | -- | -- | -- |
| | Mean: | 1.08 | 1.20 | 2.36 | 0.64 | 0.81 | 1.22 |

Table A-8. CPUE and vulnerability (estimate of catchability, *q*) of fish in John Day Reservoir by species, gear, size during 1983-1986 (From Vigg et al. In Preparation)

| Species | Gear/ Fish Size (mm) | CPUE | Vulnerability (Recap:Free) (est. of *q*) | R.A. Index (CPUE/*q*) |
|---|---|---|---|---|
| Northern squawfish | | | | |
| | Electro. | | | |
| | 250-400 | 0.427 | 0.00739 | 57.82 |
| | >400 | 0.449 | 0.02045 | 21.95 |
| | Gill net | | | |
| | 250-400 | 1.171 | 0.00448 | 261.63 |
| | >400 | 0.422 | 0.00810 | 52.10 |
| | Trap net | | | |
| | 250-400 | 0.896 | 0.00638 | 140.48 |
| | >400 | 0.648 | 0.00871 | 74.42 |
| | Angler | | | |
| | 250-400 | I.37 | 0.00179 | 765.23 |
| | >400 | 1.81 | 0.00668 | 270.84 |
| Walleye | | | | |
| | Electro. | | | |
| | 250-500 | 0.032 | 0.02680 | 1.19 |
| | >500 | 0.093 | 0.00294 | 31.65 |
| | Gill net | | | |
| | 250-500 | 0.051 | 0.02094 | 2.44 |
| | >500 | 0.160 | 0.00269 | 59.40 |
| | Trap net | | | |
| | 250-500 | 0.021 | 0.01508 | 1.39 |
| | >500 | 0.151 | 0.00220 | 68.52 |
| | Angler | | | |
| | 250-500 | 0.0046 | 0.01005 | 0.46 |
| | >500 | 0.0144 | 0.00245 | 5.88 |

Table A-8. continued

| Species | Gear/ Fish Size (mm) | CPUE | Vulnerability (Recap:Free) (est. of $q$) | R.A. Index (CPUE/$q$) |
|---|---|---|---|---|
| Smallmouth Bass | | | | |
| | Electro. | | | |
| | 200-250 | 0.518 | 0.12222 | 4.24 |
| | >250 | 0.677 | 0.05992 | 11.30 |
| | Gill net | | | |
| | 200-250 | 0.041 | 0.00145 | 28.29 |
| | >250 | 0.094 | 0.00133 | 70.59 |
| | Trap net | | | |
| | 200-250 | 0.029 | 0.00048 | 60.03 |
| | >250 | 0.144 | 0.00067 | 216.29 |
| | Angler | | | |
| | 200-250 | 0.0421 | 0.00193 | 21.79 |
| | >250 | 0.1594 | 0.00658 | 24.22 |

Table A-9. Relative abundance (percent of total catch) of adult northern squawf ish (SQF) , walleyes (WAL) , centrarchids (CEN), ictalurids (ICT), catostomids (CAT), salmon, ***Oncorhynchus*** spp. (SAL), and other species in various reservoirs in the Columbia River (from Mullan et ***al. 1986).***

| River Reach/ Reservoir/ Season | Percent by Species, Genus or Family | | | | | | |
|---|---|---|---|---|---|---|---|
| | SQF | WAL | CEN | ICT | CAT | SAL | Other* |
| Lower Columbia: | | | | | | | |
| John Day[a] | 3.2 | 0.3 | 6.2 | 0.6 | 23.4 | 5.1 | 61.2 |
| McNary[b] | 12.7 | 0.1 | 8.4 | 2.6 | 2.7 | 51.0 | 22.5 |
| Hid-Columbia: | | | | | | | |
| Chief Joseph[c] | 34.3 | 8.4 | -- | -- | 20.9 | 1.1 | 35.2 |
| Chief Joseph[d] | 29.0 | 14.0 | -- | -- | 26.0 | 3.8 | 27.2 |
| Wells[e] | 8.0 | -- | 14.7 | 1.3 | 12.8 | -- | 63.2 |
| Five Res.[f] | 22.5 | -- | 0.7 | 0.2 | 16.4 | 7.7 | 52.5 |
| Hanford[g] Reach | 12.3 | -- | 0.2 | 0.2 | 9.4 | 39.7 | 38.2 |
| Snake River: | | | | | | | |
| Four Res.[h] | 7.7 | -- | 30.4 | 4.8 | 31.2 | 0.2 | 25.7 |
| Lower Granite[i] | | | | | | | |
| Spring | 10.5 | 0.0 | 13.1 | 0.1 | 22.3 | 35.5 | 18.5 |
| Summer | 16.3 | 0.0 | 15.9 | 0.0 | 42.1 | 24.4 | 24.9 |
| Fall | 16.4 | 0.0 | 11.4 | 0.6 | 48.1 | 13.5 | 10.0 |
| Winter | 10.0 | 0.0 | 10.0 | 0.0 | 30.0 | 10.0 | 40.0 |
| Total | 13.8 | 0.0 | 14.2 | 0.1 | 34.2 | 16.9 | 20.8 |

* Other category is predominantly cyprinids

a Hjort et al. (1981)
b ***Nelson*** (1981)
c Erickson et al. (1977)
d Laumeyer (1972)
e McGee (1979)
f Dell ***et al. (1975)***
g Gray and Dauble (1978)
h Bennett ***et al. (1983)***
i Bennett et ***al. (1988)***

bottom-set gill nets in the main-stem: compared to less than 2% in the river below Beacon Rock, Bonneville Dam tailrace (USFWS 1957). In general the CPUE of northern squawfish was greater above compared to below Bonneville Dam tailrace (Table A-10; USFWS 1957).

Hydroacoustics has been used to assess fish populations in various inland waters, including juvenile salmonid population abundance near Columbia River dams (Appendix A-2). Relative abundance estimates from net sampling could be used in conjunction with hydroacoustics to index the northern squawfish populations in Columbia River reservoirs (Figure A-3). Dual-beam acoustic technology enables differentiation of fish populations by size, i.e., target stength (Thorne 1983; Burczunski and Johnson 1986). Thus it would be feasible to estimate the open water (limnetic), predaceous size 0250 mm) component of the fish population using hydroacoustics, and then apportion it into the northern squawfish segment from the percent composition of the net samples. Without the “ground truthing” from the net samples, the hydroacoustic estimate would only be an estimate of total ichthyomass or fish productivity, and one would have to assume that the proportion of northern squawfish to total fish standing crop was constant in all areas.

## Habitat

If one assumes the density of northern squawfish is homogeneous throughout the Columbia River System and equal to that estimated in John Day Reservoir, the system-wide abundance of northern squawfish would range between about 0.5 to 1.0 million (Table A-11). It is not obvious to us if reservoir length, area, or volume is the most valid ratio-multiplier for northern squawfish abundance: hut since they have a ubiquitous distribution, and are pelagic feeders -- habitat volume may be most appropriate.

An optimum thermal habitat index similar to that of Christie and Regier (1988) was test-implemented for three predator species in McNary Reservoir and five Snake River reservoirs (Table A-12). These preliminary results indicate that northern squawfish would have large optimum thermal habitat in the main-stem Columbia and species preferring warmer water would have relatively more habitat in the lower Snake River. This thermal index could be refined with a better-defined optimum thermal range, or a continuous relation based on fish growth as a function of temperature (Christie and Regier 1988), or considering a more complex relationship incorporating both mortality and growth (Pauly 1980).

The morphoedaphic index (MEI) was implemented for below Bonneville Dam, Chief Joseph Reservoir, and F.D. Roosevelt Reservoir in the Columbia River, and Ice Harbor and Lower Granite reservoirs in the Snake River (Table A-13). Although these data are quite limited, one can observe considerable variation in potential fish productivity between the upper and lower Columbia River system; i.e., higher total productivity in the lower river.

Table A-10. Catch per unit effort of northern squawfish in various Columbia River locations during 1955-1956 (from USFWS 1957).

| Gear/ Location | Effort | Northern squawfish | | Other Species | |
|---|---|---|---|---|---|
| | | Catch | CPUE | Catch | CPUE |
| **Mainstem Columbia** | | | | | |
| Drift Gill net: [a] | | | | | |
| Astoria | 46 | 0 | 0.00 | 270 | 5.87 |
| Cathalamet | 39 | 3 | 0.08 | 70 | 1.79 |
| St. Iiellens | 39 | 5 | 0.13 | 67 | 1.72 |
| Portland | 41 | 6 | 0.15 | 79 | 1.93 |
| Beacon Rock | 38 | 36 | 0.95 | 62 | 1.63 |
| Cooks | 33 | 15 | 0.45 | 53 | 1.61 |
| Lyle | 32 | 4 | 0.13 | 94 | 2.94 |
| Bottom-set Gill net: [b] | | | | | |
| Astoria | 14 | 0 | 0.00 | 5,005 | 357.50 |
| Cathalamet | 19 | 4 | 0.21 | 404 | 21.26 |
| St. Hellens | 38 | 63 | 1.66 | 1,273 | 33.50 |
| Portland | 33 | 54 | 1.64 | 471 | 14.27 |
| Beacon Rock | 41 | 415 | 10.12 | 1,229 | 28.98 |
| Cooks | 31 | 236 | 7.61 | 856 | 27.61 |
| Near Wind River | 10 | 85 | 8.50 | 165 | 16.50 |
| Spring Creek Eddy | 27 | 394 | 14.60 | 680 | 25.19 |
| Lyle | 34 | 343 | 10.09 | 1,008 | 29.65 |
| Confluence of Tributary Streams | | | | | |
| Bottom-set Gill net: [c] | | | | | |
| Big Cr. | 14 | 1 | 0.07 | 757 | 54.07 |
| Grays R. | 12 | 1 | 0.08 | 226 | 18.83 |
| Elokomin R. | 12 | 41 | 3.42 | 421 | 35.08 |
| Abernathy Cr. | 14 | 9 | 0.64 | 470 | 33.57 |
| Germany Cr. | 2 | 7 | 3.50 | 43 | 21.50 |
| Clatskanie R. | 14 | 4 | 0.29 | 216 | 15.43 |
| Coweman R. | 15 | 45 | 3.00 | 928 | 61.87 |
| Lewis R. | 15 | 47 | 3.13 | 385 | 25.67 |
| Kalama R. | 14 | 35 | 2.50 | 488 | 34.86 |
| Washougal R. | 15 | 35 | 2.33 | 433 | 28.87 |
| Eagle Cr. | 13 | 90 | 6.92 | 169 | 13.00 |
| Herman Cr. | 16 | 112 | 7.00 | 229 | 14.31 |
| Wind R. | 13 | 86 | 6.62 | 64 | 4.92 |
| Big W.S.R. | 13 | 61 | 4.69 | 229 | 17.62 |
| Hood R. | 15 | 75 | 5.00 | 137 | 9.13 |
| Klickitat R. | 12 | 41 | 3.42 | 250 | 20.83 |
| John Day R. | 13 | 197 | 15.15 | 660 | 50.77 |
| Umatilla R. | 16 | 83 | 5.19 | 797 | 49.81 |

[a] 9 x 400 ft variable mesh net set for 30 minutes
[b] 8 x 200 ft variable mesh net set overnight
[c] a-variable mesh gill nets (4 x 100 ft and 8 x 120 ft) set overnight

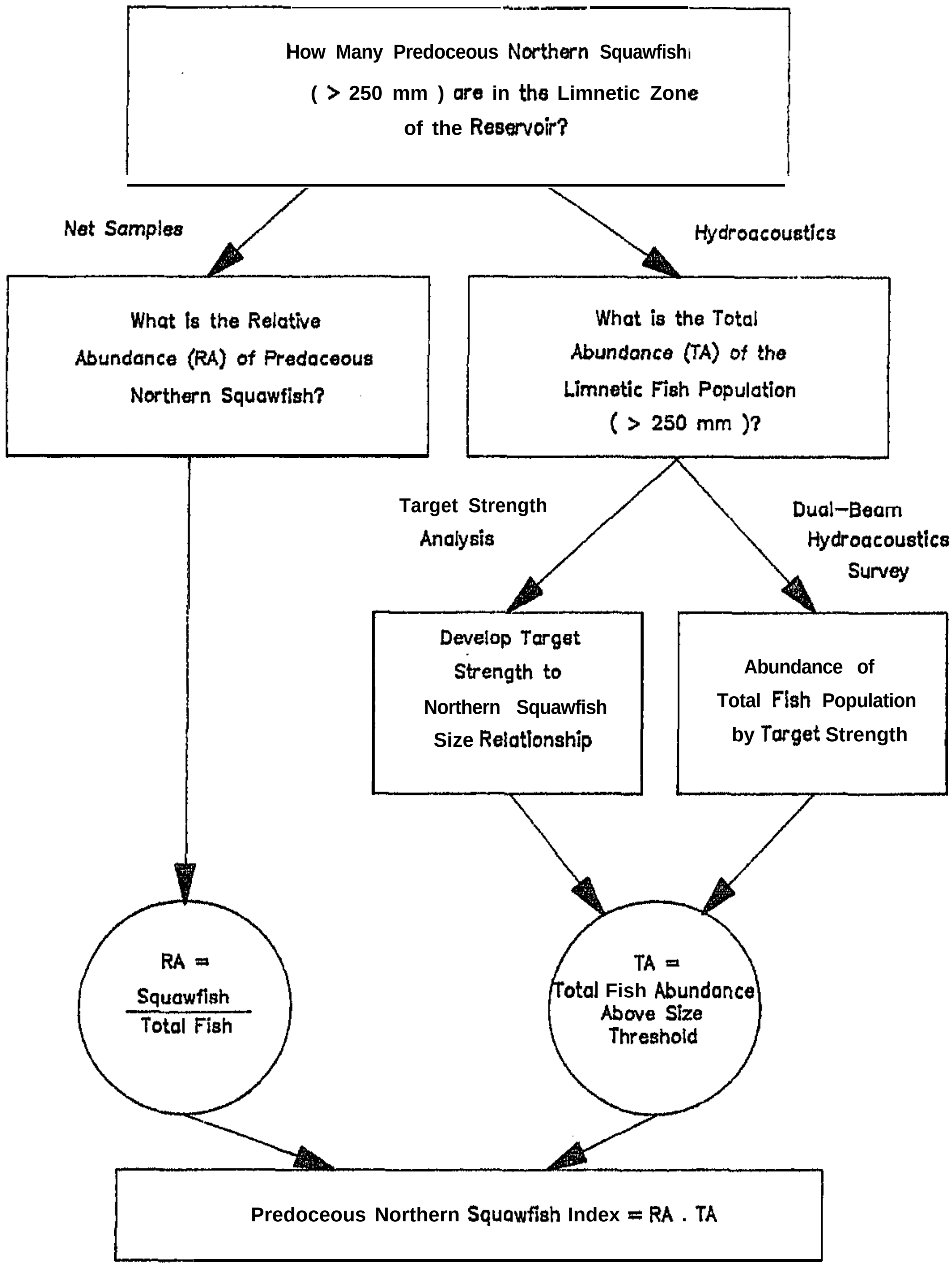


Figure A-3. Flow chart of methodology to estimate the abundance of predaceous northern squawfish 0250 mm) in the limnetic zone (off-shore, open-water) of a reservoir using hydroacoustics and net samples.

Table A-11. Comparison of three methods to index northern squawfish predation, assuming a direct relationship with quantity of habitat: numbers are based on population estimates of 85,316 northern squawfish >250 mm in John Day Reservoir from Beamesderfer and Rieman (1988a).

| River Mile | Project | Predation Index (numbers) | | |
|---|---|---|---|---|
| | | Length | Area | Capacity |
| Columbia: | | | | |
| 0 | Estuary | 162,480 | | |
| 145.5 | Bonneville | 51,592 | 34,809 | 20,339 |
| 191.7 | The Dalles | 26,689 | 17,916 | 11,969 |
| 215.6 | John Day | 85,316 | 85,316 | 85,316 |
| 292 | McNary | 68,119 | 65,011 | 48,598 |
| 353 | Hanford Reach | 49,135 | | |
| 397 | Priest Rapids | 20,101 | 11,944 | 7,164 |
| 415 | Wanapum | 42,435 | 23,547 | 21,131 |
| 453 | Rock Island | 23,451 | 4,266 | 4,093 |
| 474 | Rocky Reach | 46,678 | 15,698 | 15,479 |
| 515.8 | Wells | 32,608 | 18,258 | 10,800 |
| 545 | Chief Joseph | 58,069 | 13,309 | 18,575 |
| 597 | Grand Coulee | 167,505 | 136,506 | 344.219 |
| 147 | | | | |
| | Total: | 834.116 | 426,580 | 587,680 |
| Snake: | | | | |
| 9.7 | Ice Harbor | 35,623 | 14,214 | 14,651 |
| 41.6 | Lower Monumental | 32,049 | 11,501 | 13,571 |
| 70.3 | Little Goose | 41,541 | 16,927 | 13,139 |
| 107.5 | Lower Granite | 59,185 | 15,186 | 17,423 |
| 160.5 | | | | |
| | Total: | 168,399 | 57,827 | 58,785 |
| Overall Total: (not including estuary) | | 1,002,575 | 484,407 | 646,465 |

Table A-12. Thermal index based on degree days at predator-specific optimum temperature and reservoir volume.

| Reservoir | Predator species | Optimum Thermal Range (C)[a] | Thermal Units, TU (degree-days) | Thermal Index (TU • volume . $10^9$) |
|---|---|---|---|---|
| McNary | N. Squawfish | 17-21 | 1.691.4 | 2.28 |
| | Walleye | 18-22 | 1,463.3 | 1.98 |
| | S.M. bass | 23-27 | 0 | 0 |
| Ice Harbor | N. Squawfish | 17-21 | 975.4 | 0.40 |
| | Walleye | 18-22 | 1,633.5 | 0.66 |
| | S.M. bass | 23-27 | 0 | 0 |
| Lower Monumental | N. Squawfish | 17-21 | 971.8 | 0.37 |
| | Walleye | 18-22 | 1.363.3 | 0.51 |
| | S.M. bass | 23-27 | 0 | 0 |
| Little Goose | N. Squawfish | 17-21 | 824.9 | 0.36 |
| | Walleye | 18-22 | 1,242.3 | 0.51 |
| | S.M. bass | 23-27 | 0 | 0 |
| Lower Granite | N. Squawfish | 17-21 | 793.5 | 0.36 |
| | Walleye | 18-22 | 1.179.9 | 0.51 |
| | S.M. bass | 23-27 | 46.6 | 0.02 |
| Dworshak | N. Squawfish | 17-21 | 0 | 0 |
| | Walleye | 18-22 | 0 | 0 |
| | S.M. bass | 23-27 | 0 | 0 |

[a] Vigg et al. (1988); Christie and Regier (1988); Thorton and Lessem (1978)

Table A-13. Morphoedaphic index (MEI) applied to F.D. Roosevelt Reservoir (FDR), Chief Joseph Reservoir and below Bonneville Dam in the mainstem Columbia River, and Ice Harbor and Lower Granite reservoirs in the lower Snake River; the surrogate measure of conductivity is used instead of total dissolved solids.

| Area | River Mile | Mean Depth (feet) | Mean Conductivity (umho/cm @ 25 C) | ME1 | Reference |
|---|---|---|---|---|---|
| Columbia River: | | | | | |
| Below Bonneville | 54-166 | 20.0 | 304 | 15.2 | Clark and Snyder (1970) |
| Chief Joseph Reservoir | 545-597 | 66.2 | 95 | 1.4 | Erickson *et al.* (1977) |
| FDR Tailrace | 596 | 20.0 | 113 | 5.7 | Stober *et al.* (1981) |
| FDR Reservoir | 597-747 | 119.5 | 110 | 0.9 | Stober *et al.* (1981) |
| Snake River: | | | | | |
| Ice Harbor Reservoir | 10-42 | 48.9 | 160 | 3.3 | Funk et al. (1985) |
| Lower Granite Reservoir | 108-161 | 54.4 | 320 | 5.9 | Funk *et al.* (1985) |

Many other habitat models exist which could be used to assess potential fish productivity relevant to predation management (Appendix ***A-4).*** The U.S. Fish and Wildlife Service has developed two types of habitat modeling approaches (Amour et al. 1984): (1) the Habitat Evaluation Procedures (HEP) are designed for quantifying habitat values and documenting impacts of habitat changes on fish and wildlife resources ; (2) the Instream Flow Incremental Methodology (IFIM) is specifically designed for simulating and quantifying impacts of changes in flow, channel morphology, or water quality, resulting from water management or stream channelization activities. IFIM was developed primarily to negotiate and design water flow regimes in free flowing streams related to fish mitigation for habitat alteration -- and thus is not directly relevant to reservoir predation management.

HEP is a computerized method for use in habitat inventory, planning, management, impact assessment, and mitigation studies (Amour ***et al. 1984).*** The method consists of a basic accounting procedure that combines habitat quality (Habitat Suitability Index, HSI) with habitat area to calculate the Habitat Units (HU). The accounting procedure enables comparisons of habitat availability at several sites (baseline) or for changes of habitat over time relative to management actions (impact assessment). The HSI is an aggregate of Suitability Indices (SI) for various habitat variables (e.g., flow, turbidity, dissolved oxygen, salinity, and temperature). The HSI is linearly related to the carrying capacity of a habitat (USFWS 1981), and is therefore a measure of potential productivity of a fish species at a given site. A single, standard species HSI model for all HEP applications is not possible, and different models are needed for different applications and site-specific conditions (Amour ***et al. 1984).*** Critical habitat information and off-site HSI models have been developed for several fish species resident in the Columbia River: e.g., walleyes, McMahon ***et al. (1984);*** smallmouth bass, Paragamian (1981), Edwards ***et al.*** (1983), McClendon and Rabeni (1987); largemouth bass (*Micropterus salmoides*), Stuber ***et al.*** (1982); channel catfish, USFWS (1981), McMahon and Terre11 (1982), Layher and Maughan (1984, 1985); and carp (*Cyprinus carpio*), Edwards and Twomay (1982). HEP output consists of quantitative information for a species -- in terms of all life stages or for a given life stage.

## Relations between predation and environmental variables

### Modeling ecological relations

The predator-prey modeling workshop steering committee, Dr. James Petersen, Chairman, coordinated a workshop at Friday Harbor, Washington on May 16-19, 1989. The results and conclusions of this workshop were documented by Fickeisen ***et al. (1989).*** A subcontract has been developed with Dr. L.J. (Sam) Bledsoe for modification of Columbia River Ecology Model (CREM) to be used as a tool for evaluation of predator control fisheries. We completed a manuscript which quantifies the relation between maximum consumption and temperature for northern squawfish (Vigg and Burley 1989; Appendix A-6).

### Year class strength

A summary of factors regulating year class strength and compensatory mechanisms are summarized in Table A-14. Temperature and food availability are generally considered to be important factors; and flow and water level during reproduction and rearing for some species. Electric Power Research Institute (EPRI) recently funded a three volume series of literature reviews on compensatory mechanisms in fish populations: these reviews include case histories of exploited populations (Saila et al. 1987), catastrophic impacts (Jude et al. 1987), and mathematical models for fish compensation (Cheng 1987).

## Field Sampling

### Species and Size Composition

A total of 165 bottom gill net sets (including 6 non-standard sets) were deployed with, 118 northern squawfish and 14 walleyes caught (Appendix A-7). Incidental (non-target species) catches were: 503 bridgelip and largescale suckers, ***Catostomus*** spp.; 75 American shad, ***Alosa sapidissima;*** 54 white sturgeon, ***Acipenser transmontanus; 48*** bullhead and channel catfish, Ictalurus ***spp.:*** 16 chiselmouth, ***Acrocheilus alutaceus;*** 9 smallmouth bass: 4 coho and sockeye salmon, ***Oncorhynchus*** spp.; 4 carp; 3 yellow perch, ***Perca flavescens;*** and 2 white and black crappies, ***Pomoxis spp..*** We collected 443 additional northern squawfish angling at McNary Dam Tailrace. The mean length of the northern squawfish (Figure A-4A) and walleyes (Figure A-5A) caught by gill nets were 345 mm, (SD= 55.5), and 412 mm (SD= 52.2), respectively. The mean length of northern squawfish (Figure A-6) caught at McNary Dam angling was 408 mm (SD= 2.1).

A two-way analysis-of-variance (ANOVA) detected significant differences in mean northern squawfish length by both time and location ($p \leq 0.005$); i.e., between the early (May 22 to June 28) and late (July 5 to August 11) periods, and between fish caught with angling at McNary Dam tailrace versus those caught with gill nets in the reservoir (Table A-15). We also found significant differences in mean length between male and female northern squawfish caught in bottom gill nets using a one way ANOVA ($p= 0.0005$). No ANOVAs were conducted on walleyes' lengths due to the negligible catches.

The mean weight of northern squawfish (Figure A-48) and walleye (Figure A-5B) were 564 g (n= 117, SD= 288.8), and 945 g (n= 14, SD= 52.2) respectively. The mean weight of northern squawfish caught angling at McNary Dam was 979 g (n= 443, SD= 318).

### Catch Per Unit Effort (CPUE)

Excluding the non-standard sets (e.g., overnight), a total of 159 bottom gill net sets of l-3 h duration were made, with a total of 89

Table A-14. Summary of factors regulating fish populations and potential compensatory mechanisms.

| Species | Criteria | Factors | Site | Reference (Appendix A-5) |
|---|---|---|---|---|
| Walleye | YCS* | competition, predation | Lake Nipissing, Ontario, Canada | Anthony & Jorgensen (1977) |
| | | water temperature | Lake Erie, Michigan | Busch *et al.* (1975) |
| | | water levels, brood stock abundance | Rainy Lake, Ontario | Chevalier (1977) |
| | | food abundance, cannibalism | Oneida Lake, New York | Forney (1974) |
| | | inter- and intra-specific competition, prey abundance | Oneida Lake, New York | Forney (1977b) |
| | | predation, alternate prey, cannibalism | Oneida Lake, New York | Forney (1976) |
| | | water levels, temperature, wind velocity | Kabetogama, Namakan, sandy point & Rainy Lakes, Ontario | Kallemeyn (1987) |
| | | fall fingerling density | Escanaba Lake, Wisconsin | Kempinger & Carline (1977) |
| | | water temperature, early life-history phases | Summary of many lakes | Koonce *et al.* (1977) |
| | | food abundance | Rockwood Fish Hatchery, Manitoba | Li & Mathias (1982) |
| | | water temperature, food abundance | Columbia River, Oregon & Washington | Maul & Horton (1985) |
| | | food abundance, walleye density | Lake Erie, Ohio, Michigan 6 Ontario | Muth & Wolfert (1986) |
| | | food abundance (mayfly emergence) | Savanne Lake, Ontario | Ritchie & Colby (1988) |

Table A-14. Continued

| Species | Criteria | Factors | Site | Reference |
|---|---|---|---|---|
| Walleye | YCS | food abundance | Escanaba Lake, Wisconsin | Serns (1982) |
| | | storage ratio (water level) | eight Kansas reservoirs | Willis & Stephen (1987) |
| | Com* | fecundity, food availability | Henderson & Savanne Lakes, Thunder bay, Ontario | Baccante & Reid (1988) |
| | | commercial fisheries | Lake of the woods, Minnesota | Carlander (1949) |
| | | predation, competition, food availability | Wilson Lake, Minnesota | Johnson (1977) |
| | | intra-specific competition, predation | Big, Pike, Hungry Jack, & Two Island Lakes, Minnesota | Johnson & Hale (1977) |
| Largemouth bass | YCS | water temperature, food abundance, fingerling bass density | Lake George, Minnesota | Kramer & Smith (1960) |
| | | brood stock size | two Mississippi reservoirs | Miranda & Muncy (1987) |
| Smallmouth bass | YCS | temperature, early life stages | many North American lakes | Shuter et al. (1980) |
| American shad | YCS | early life mortality, abundance | Connecticut River, Mass. & Conn. | Crecco et al. (1983) |
| Striped bass | YCS | river flows | Sacramento-San Joaquin Estuary, California | Stevens (1977) |
| | | water temperature | Hudson River Estuary, New York | Dey (1981) |

Table A-14. Continued

| Species | Criteria | Factors | Site | Reference |
|---|---|---|---|---|
| Yellow perch | YCS | predation | Oneida Lake, New York | Forney (1971) |
| | Syn* | population density, food availability | twelve lakes in Quebec | Boisclair & Leggett (1989) |
| Sockeye salmon | Smo* | turbidity euphotic zone | Alaskan lakes and streams | Lloyd et *al.* *(1987)* |
| Chinook salmon, American shad, delta and longf in smelt | YCS | river flow during spawning and nursery periods, dispersal of young | Sacramento-San Jouquin River System, California | Stevens & Miller (1983) |
| Salmon | Smo | review of various factors | Columbia River and ocean | Diamond & Pribble (1978) |
| Salmon & resident fish community | Smo | dams & associated factors | Mid-Columbia River | Mullan et *al.* *(1986)* |

* YCS= Year Class Strength
Com= Compensation
Syn= Synecology
Smo= smolt production and survival

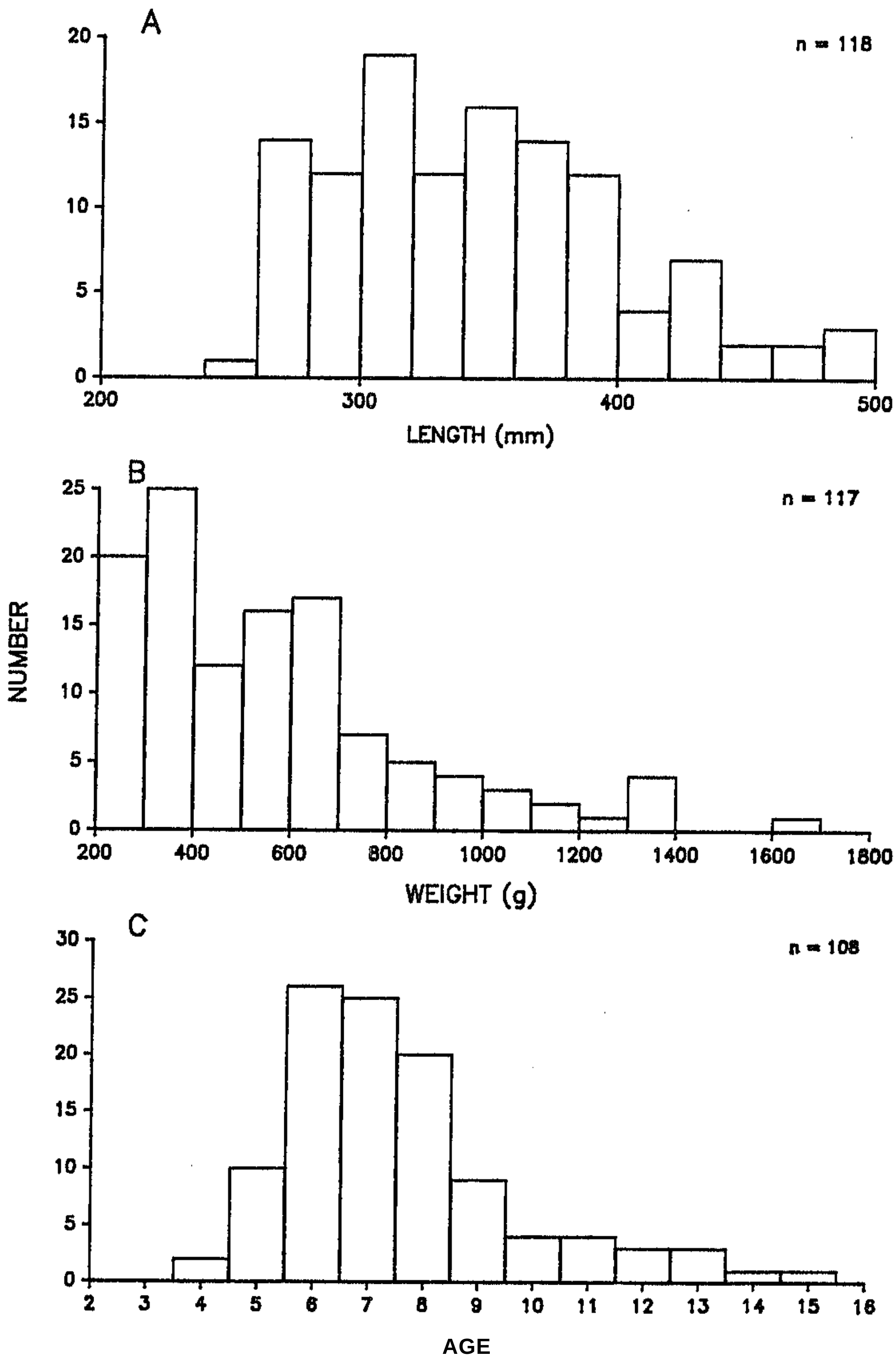


Figure A-4. Frequency distribution of northern squawfish by (A) length, (B) weight and (C) age from bottom gill nets in John Day Reservoir, May 22 to August 8, 1989.

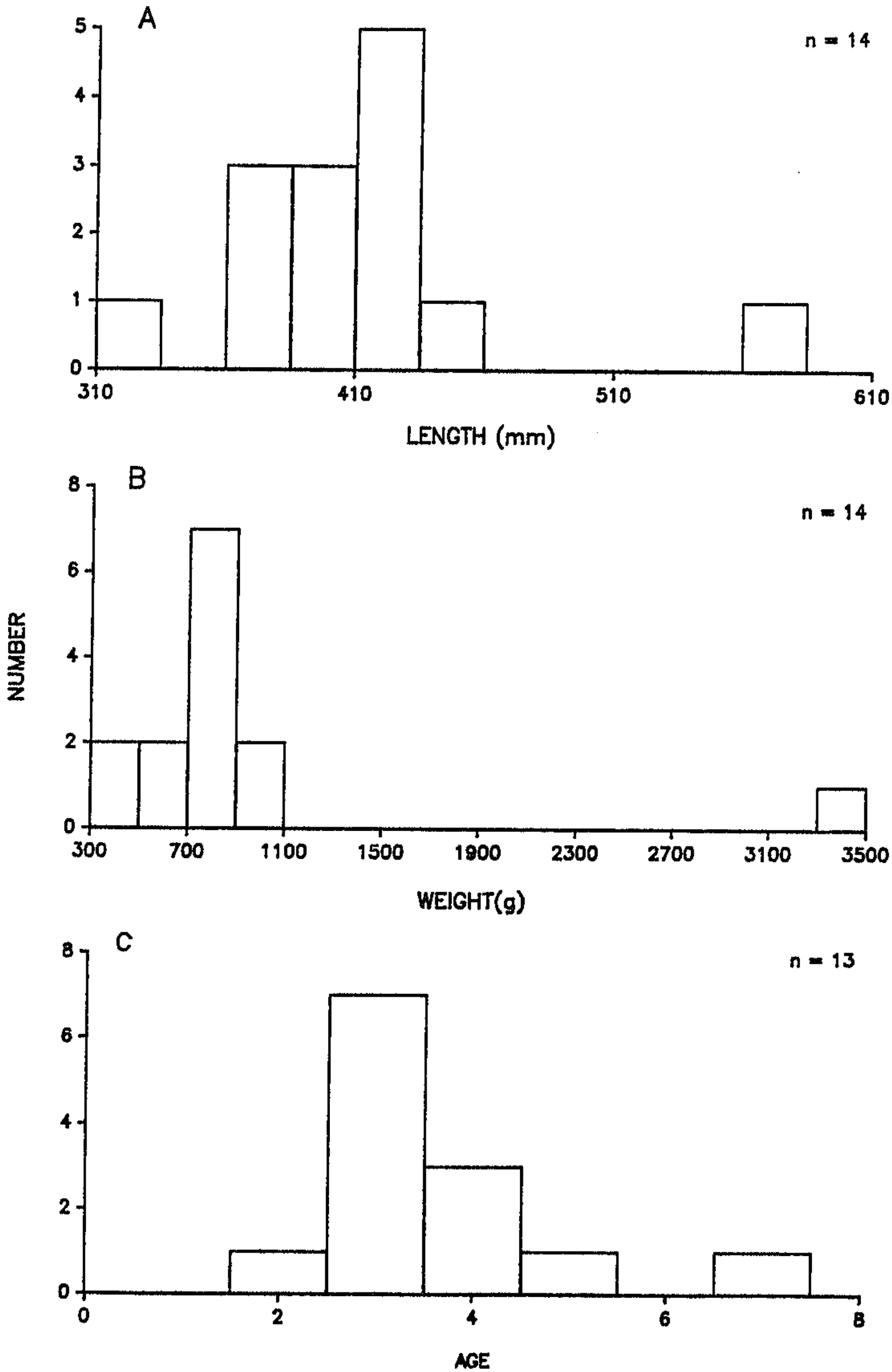


Figure A-5. Frequency distribution of walleye by (A) length, (B) weight and (C) age from bottom gill nets in John Day Reservoir, May 22 to August 8, 1989.

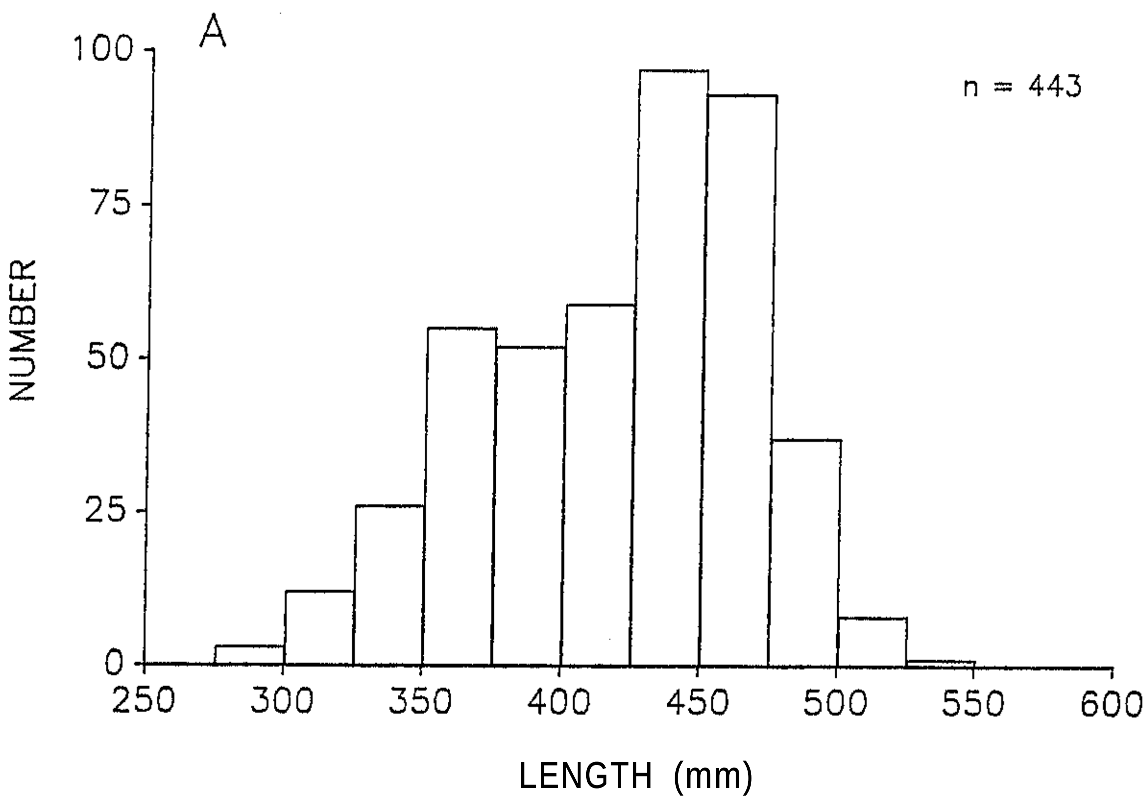


Figure A-6. Frequency distribution of northern squawfish length from angling at McNary Dam tailrace, June 21 to August 9, 1989.

Table A-15. Mean length (mm) for northern squawfish by early and late time periods and reservoir *area:* 95 percent confidence intervals (C.I.) for *means* are in parentheses (n= 532).

| Time Period | Dates | Statistic | Area (sampling method) | |
|---|---|---|---|---|
| | | | Reservoir (gill net) | Tailrace BRZ (angling) |
| Early | May 22 to June 28 | Mean Length (C.I.) | 333 (314-352) | 439 (429-450) |
| | | Sample Size | 25 | 84 |
| Late | July 5 to Aug 8 | Mean Length (C.I.) | 349 (337-361) | 417 (412-422) |
| | | Sample Size | 64 | 359 |

northern squawfish and 6 walleyes caught (Appendix A-7). This translated into an overall catch per unit effort (CPUE) of 0.27 fish per net hour for northern squawfish and 0.018 fish per net hour for walleyes. The mean CPUE for hook and line angling from McNary Dam tailrace was 12.6 fish per angler-hour (n= 6, SD= 4.5).

We found no significant difference ($p > 0.05$) in mean bottom gill net CPUE of northern squawfish by sampling time period or area: i.e., early (22 May to 28 June) and late (5 July to 8 August) periods, and upper (McNary and Irrigon) and lower (Arlington and John Day Forebay) using a two-way ANOVA.

## Age Determination

Northern squawfish (n= 108) caught in the bottom gill nets had a mean age of 8 (SD= 2.3). Walleyes (n= 13) sampled had a mean age of 4 (SD= 1.3). The age distributions of northern squawfish and walleyes are presented in Figure A-4C, and Figure A-5C, respectively.

## Year Class Strengths

Several methods for analyzing year class strength were evaluated. A brief summary of each method follows:

### *Iiile (1941)*

Hile (1941) looked at the fluctuations in the relative abundance of year classes of rock bass, *Ambloplites rupestris* (Rafinesque) in Nibish Lake, Wisconsin. He used catch data from hook and line sampling, and large mesh gill nets. Only aged fish were used in the analysis of year class strengths. A tabulation of the age and year class composition data for each capture year was made. The number fish caught of each age group for a cohort were totaled. The totals were summed and averaged. A percent year class value was assigned based on all collections combined. The percent values for each *year* class were used as the basis for qualitative determination of relatively rich or poor year classes. Hile (1941) states, however that the data do not provide an exact measure of the true relative strength of the year classes -- because the age groups are not uniformly represented in each year class.

The assumptions made were: that methods of fish collection were similar, and comparable between catch years.

### *El -Zarka (19591*

The El-Zarka (1959) method is an adaptation of the method used by Hile (1941) to estimate annual fluctuations in growth rate. El-Zarka (1959) used the modified “Rile” method to assess the year class strengths of yellow perch, *Perca flavescens* (Mitchill), in Saginaw Bay, Lake Huron. The procedure is based on a series of comparisons in which the abundance of each year class is estimated in terms of the strength of the preceding one. Fish were collected each capture year using commercial trap nets, fyke nets, and other gear (a minor percentage). All the fish used for year class strength analysis were aged and came from the samples collected during May or early June. The data *were* arranged into a table by capture date and year class. Each year class strength was estimated by comparing the age groups represented in that year class with the same age groups represented in the preceding year class. The year prior to the first year class data is given an arbitrary value of zero, and successive year classes are determined by the successive addition of the percentage difference between year classes. This percentage difference is then subtracted from the overall mean percent difference to arrive at the year class strength index.

The assumptions made for this method were that fish were equally vulnerable to the gear throughout the sample season and in all years compared.

### *Extrapolation Method -- Gulland (1983)*

Gulland (1983) discusses a method of estimating relative year class strength. The procedure uses catch per unit effort (CPUE) data for individual year classes plotted on a logarithmic scale, against age (cohort analysis). The CPUE at a given age at recruitment can be read from this graph. The values at that given age for each year class can then be used as the index.

### *Absolute Estimate of Year Class Strengtb modified from Gulland (1983)*

This method was modified from Gulland (1983), where he used the equation:

$$N = R / Z$$

where N is the average number in the stock, R is the recruitment, and Z is the mortality estimate. We modified this equation to be:

$$N_0 = e^{(\ln N_t + Z)}$$

where $N_0$ is the estimated absolute year class strength, $N_t$ is the number of fish at some age t, and $Z$ is the cumulative mortality of age t fish ($Z = -\ln(S)$). For this method an estimate of the population abundance and an estimate of the cumulative mortality are needed.

### *Rieman Residual Method from Rieman and Beamesderfer (1988)*

The ***Rieman Method*** uses a regression approach to estimate relative year class strengths from the decending limb of annual catch curves. A mortality estimate is made for the annual catch, and the residuals of individual age groups are the basis of the relative year class index.

This method is based on the fact that moderate deviations from the general form of the catch curve (given adequate sample size and constant mortality) do not invalidate the relation -- but can be attributed to fluctuations in year class strength (Ricker 1975). Assumptions made using this method were: constant and equal mortality among all ages, and that all ages compared were fully recruited to the gear. The *Rieman* ***Method*** uses a semi-log relation between the log number of fish and age. The index ($I_r$) is simply a transformation of the residuals back to an arithmetic scale, using the antilog of the natural log residuals:

$$I_r = e^{(\ln N_d - \ln N_p)}$$

where, Nd is the arithmetic value of the individual data point (age-specific CPUE) from the decending limb of the catch curve, and and $N_p$ is the predicted value for that age using the mortality rate equation derived from linear regression:

$$\ln(N_p) = \ln a + b(A)$$

where, a and b are empirical coefficients (e.g., for northern squawfish, ln a= 11.2932 and b= -2.133721, and A is fish age. The back-transformed residuals were then standardized to a mean of zero and these standardized values were used as the index. To evaluate the utility of the various indices we will correlate the index values with the hypothetical population data in the spreadsheet models.

## Predator Control Fishery Development & Evaluation Plan

A preliminary plan to implement predation indexing and test fisheries in John Day Reservoir and selected Hydroelectric Projects is presented in Appendix A-8. The ***Predation Index*** is a relatively low-cost, rapid assessment, order of magnitude measure of predation. The primary purpose of the predation index is to determine the priority of predation problem throughout the Columbia River Basin, and to direct the implementation of the predator control fisheries. The measured approach of stepwise implementation of the predation index and predator control fisheries is presented in Figure A-7.

A ***"Test Fishery"*** is proposed for implementation in John Day Reservoir and selected project-specific "predation hotspots" in 1990. The test fishery would have three components: (1) a commercial-bounty fishery, (2) a sport-bounty fishery, and (3) dam angling. The purpose of implementing these three types of fisheries on a small-scale experimental basis is to determine which type(s) are most effective and should be included in the system-wide predator control program. The test fishery should not be confused with Dr. Mathews' harvest technology study (Report C, This Volume) which will determine which type of fishing gear is most appropriate for a small boat limited entry commercial fishery. A step-down plan for test fishery implementation is presented in (Figure A-8). These plans are currently under development and will continue to evolve as more input is received and integrated with Dr. Hanna's feasibility study (Report B, This Volume).

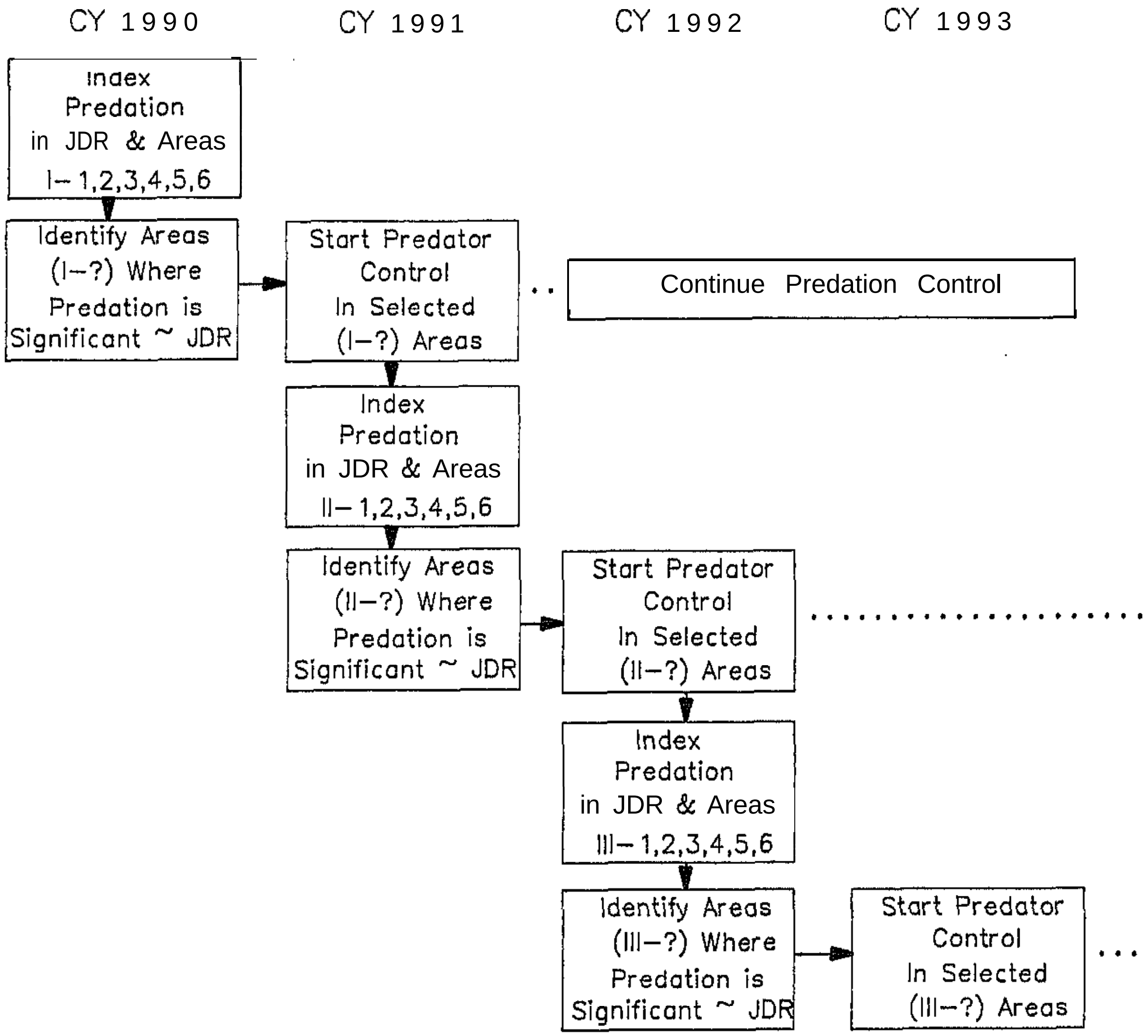


Figure A-l. **Stepwise** implementation plan for predation indexing and predator control fisheries.

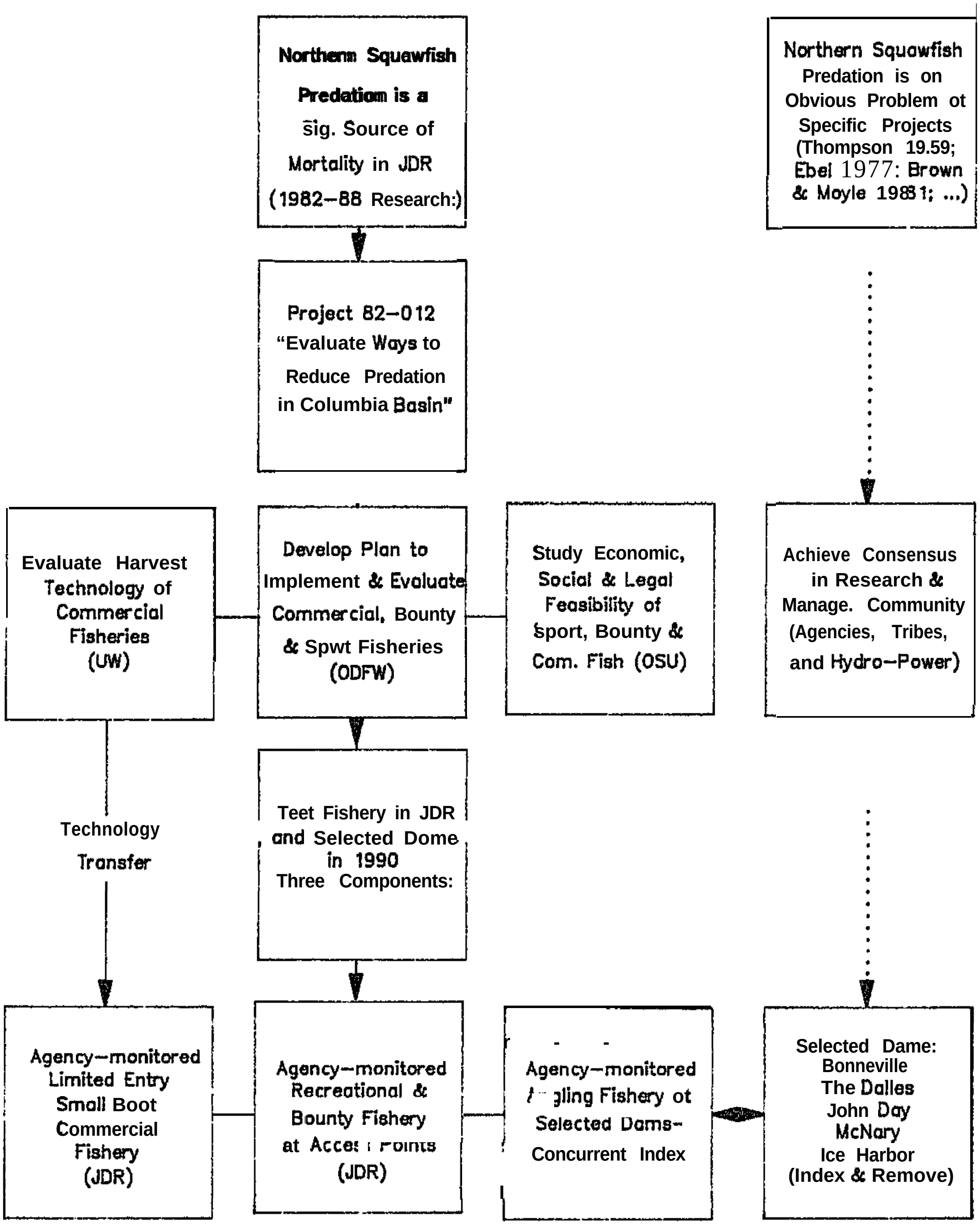


**Figure A-8. Predator-Prey Project** strategy for implementation of small boat commercial and sport-bounty test fisheries in John Day Reservoir: and dam angling removal fisheries and concurrent indexing at project-specific sites in 1990.

Three levels of evaluation of the effects of a predator removal program are possible, based on different criteria: (1) changes in fish predator populations, (2) juvenile salmonid survival, or (3) subsequent adult returns. The inherent problems in the methodology of mark-recapture experiments and the resultant variability of the survival estimates (and sometimes unrealistic results) precludes direct estimation of changes in juvenile survival at present, although this may be feasible in the future (Burnham et al. 1987). Evaluation based on the ultimate criterion of adult returns is problematical because: a long time series would be required to quantify the correlation between predator removal and adult returns: correlation does not prove causation: and, many other variables besides in-reservoir mortality (e.g., estuarine and ocean mortality factors) affect the survival of salmonids from the time smolts migrate past Bonneville Dam until adults return there. For example, survival of summer chinook salmon, from smolts to adults, can vary about 400% -- caused by variations in ocean survival due to factors which cannot be accurately assessed, e.g., El Niño events, coastal upwelling, predator-prey abundance, and condition of hatchery fish (Raymond 1988).

We therefore consider the targeted northern squawfish population (and other predators) as the appropriate level for direct monitoring of the effectiveness of a predator removal program. Components of the biological evaluation would include (1) size (age) structure, (2) trends in population abundance, and (3) biological intra- and inter-specific compensation. Simulation modeling will be used to predict the effect of changes of predator abundance and size (age) composition on juvenile survival, and ultimately (if ocean dynamics could be modeled) adult returns. The modeling will be integrated with monitoring of the control fisheries and additional experimentation in order to build more sophisticated models as our knowledge increases -- and thus make management decisions based on the best understanding of the system (Figure A-9).

Objectives of the evaluation plan are to determine: (1) how the size structure, relative abundance, consumption rate and distribution of northern squawfish populations respond to planned removal programs: (2) how population dynamics parameters (growth, reproduction, and mortality) of northern squawfish respond to planned removal programs; (3) if predatory compensation occurs within the fish community, i.e., if increased predation by other fish predators (e.g., walleye, channel catfish, and smallmouth bass) compensates for reduction in predation by northern squawfish; and (4) if decreases in northern squawfish densities causes increased survival of juvenile salmonids.

Approaches included in the proposed evaluation plan are: (1) conduct field studies and monitoring of removal fishery before, during and after predator (northern squawfish) removal to evaluate the structure and dynamics of the predator populations: (2) use modeling as a tool to predict the biological consequences of predator removal, and identify data needs for comprehensive evaluation: and (3) determine the feasibility of controlled experiments (laboratory and mesocosm) to determine cause-effect relations between predator density and juvenile

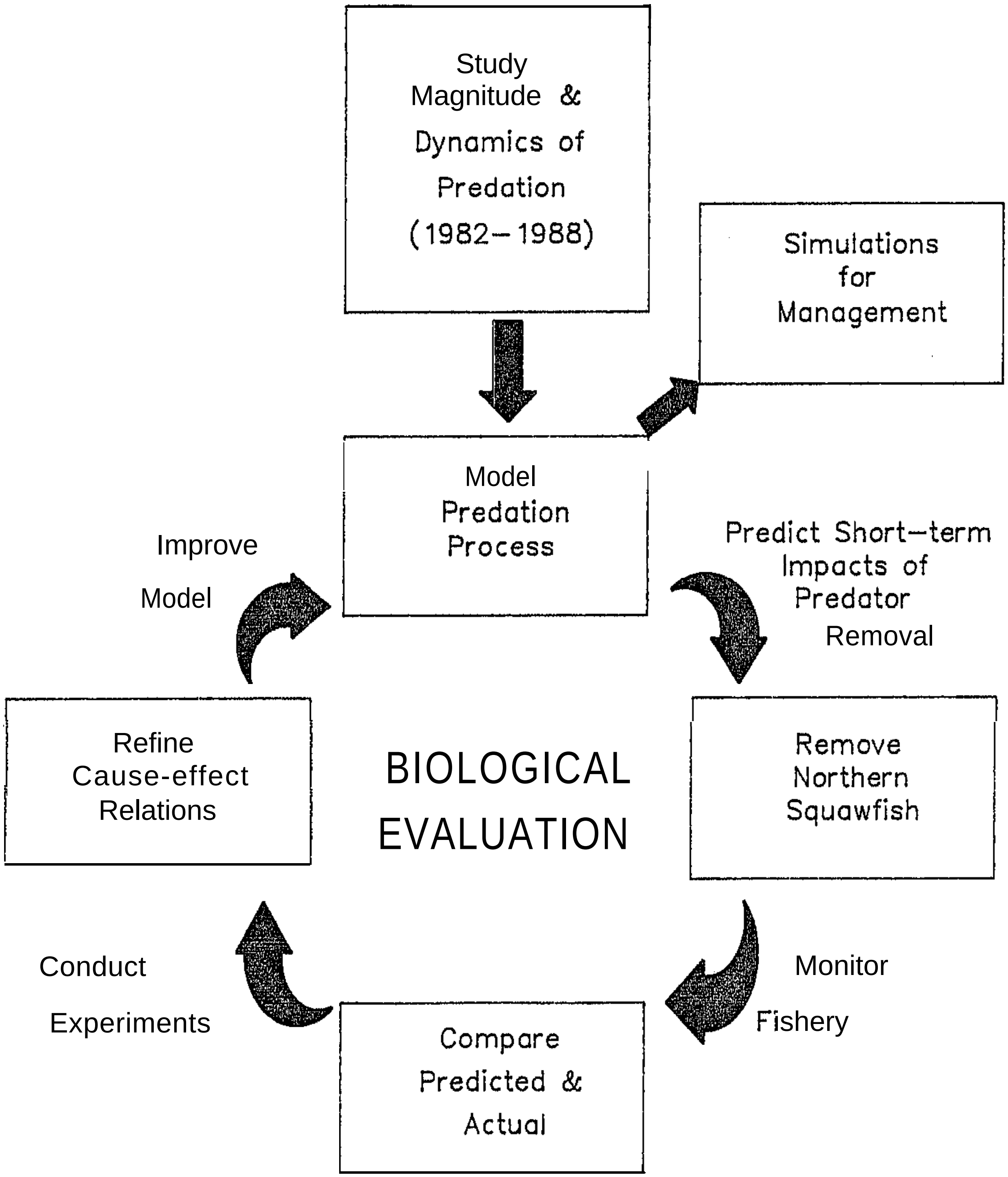


Figure A-9. Biological evaluation of predator control fisheries -- incorporating simulation modeling.

salmonid survival. The recommended approach integrates field studies on predator population dynamics, ecological modeling, and controlled experimentation in order to understand the cause-effect mechanisms and to evaluate the proximate biological consequences of predator removal. Additional work is needed to determine the feasibility of using small scale (laboratory) or medium scale (mesocosm) experiments to quantify the cause-effect relations between predator density and juvenile salmonid survival.

## DISCUSSION

### Predation Index

Fish stock assessment methods can be divided into two categories: (1) direct, e.g., yield of commercial fisheries, population estimates, and monitoring of CPUE; and (2) indirect, e.g., potential fish productivity indices based on lower bio-trophic levels (primary, secondary) or the environment (physical, chemical). Direct methods are most applicable when there is ongoing research or a historical data base, and when accurate and realistic estimates are required, e.g., the Great Lakes. Indirect methods are applicable when data and economic resources are lacking, and only an order of magnitude estimate is needed for management, e.g., African Lakes. The best-suited approach for indexing predation in the Columbia River will depend on the level of detail required by fishery managers. A review of available information for various predator abundance indexing approaches was presented, and more quantitative analysis of sampling design will be presented in the final report.

### Predation Questionnaire

We have received and tabulated results from primary contacts; preliminary results from secondary contacts were presented, but will be revised when all responses are received. The large degree of uncertainty associated with the questionnaire responses probably reflect the lack of data -- especially on predator abundance and predation losses. The Fish Passage Center makes annual estimates of smolt abundance at various dams and reaches; availability of these data apparently resulted in less uncertainty on this component of the "predation index". The predation questionnaire results may be helpful in planning the implementation of the predation indexing and test fishery, but should be treated as opinion and perception, not as true fact.

Using smolt abundance as a surrogate for predator consumption rate is based on the assumption that if smolts are present, northern squawfish will eat them preferentially over alternate prey; and thus the total number of juvenile salmonids consumed will be proportional to the product of predator abundance and smolt abundance. Based on a review of available literature, Brown and Moyle (1981) stated "the main ***conclusion that can be drawn from feeding habits of squawfish is that they do prey on salmonids** in some situations **and are capable of consuming them in***

*1 arge numbers"*; they also concluded that more research was necessary to determine how dams and diversion increase the impact of squawfish predation on salmonids. Recent diet composition research documented that northern squawfish preferred juvenile salmonids during their peak migratory densities in May and July in John Day Reservoir (Poe *et al.* *1988).* An electivity index demonstrated that northern squawfish selectively fed on juvenile salmonids throughout John Day Reservoir -- even though salmonids were relatively low in abundance compared to other prey fish (i.e., catostomids, percopsids, and cyprinids) which were generally selected against in the diet (Poe *et al.* 1988). Cottids were the only non-salmonid prey fish that were usually selected for. Vigg (1988, Figure 7) showed a rapid increase in the proportional mass of juvenile salmonids (relative to other prey) in the diet of northern squawfish as smolt density increased in McNary Dam tailrace; the diet rapidly reached about 80% salmonids at relatively low smolt densities and approached 100% salmonids at moderate to high smolt densities.

## Mark-recapture population estimates

The population estimates which have been done in Columbia River reservoirs have been quite variable between time periods and locations. It is important to test assumptions of a mark-recapture population estimate. Vulnerability of northern squawfish to sampling gear increases with fish size -- perhaps due to changes in feeding behavior and distribution: assuming equal vulnerability can result in a negative bias of about 20% in population abundance estimates (Beamesderfer and Rieman 1988a, 1988b). The assumption of a closed population (complete versus no mixing among areas) is probably the most crucial assumption, since its violation would result in about a ten times difference in the population estimate in John Day Reservoir (Beamesderfer and Rieman 1988b). It is necessary to test the area over which a population estimate applies by marking and recapturing fish throughout a reservoir. The Overton (1965) estimator is well suited to monitoring a predator control program since it accounts for known removals from the population.

## Catch per unit of effort (CPUE)

The spatial distribution and movements of northern squawfish within John Day Reservoir are very dynamic due to biological factors such as spawning and smolt abundance which vary greatly on a temporal basis (Beamesderfer and Rieman 1988a; Vigg 1988b). Therefore, a predator abundance index should be stratified by month and area to average out variability -- to obtain a representative sample of the entire reservoir over the season of smolt out-migration (April to September).

A multiple gear sampling approach can partially compensate for variable catchability and size-selectivity of individual sampling methods, but the biases do not necessarily cancel each other (Beamesderfer and Rieman 1988b). Electrofishing has the advantage of being an active sampling method, i.e., catches do not depend *on* the movements of the fish: however, the CPUE in John Day Reservoir varied considerably by time and area. Gill net and trap net CPUE was somewhat less variable, but since they are passive methods they depend on movements of the fish (i.e. behavior), and gill nets can be size-selective if appropriate mesh sizes are not used. Consistent sampling design and sufficient sample size is required to deal with the problem of variations in vulnerability -- these considerations should be incorporated into any long-term monitoring of fish populations (Beamesderfer and Rieman 1988b).

Mean CPUE (log transformed) is often used as an index of fish density. Bannerot and Austin (1983) present alternative statistics which may be appropriate for experimental netting programs, i.e., the transformed frequency of zero catches. Another CPUE method which may be suitable'for monitoring changes in a control fishery was presented by Dupont (1983). We will continue to evaluate methods for indexing predator abundance with CPUE, and will conduct additional analyses on required sample size and sampling design.

Percent composition of a fish species in a representative net sample provides an estimate of its relative abundance compared to the total fish community. Available data on the relative abundance of northern squawfish in various reservoirs in the Columbia Basin was reviewed, and northern squawfish apparently comprise a significant proportion of the community in the lower and mid-Columbia and the lower Snake rivers. Based on early work (1950's) northern squawfish relative abundance may be less in the river below Beacon Rock (Bonneville Dam tailrace) compared to the tailrace and reservoir above. Relative abundance from net samples alone cannot be translated into absolute numbers since that is dependent on the total numbers of fish present in a given reservoir -- which is in turn dependent on overall productivity which can vary within the system. However, by incorporating dual-beam hydroacoustic surveys with relative abundance estimates it may be possible to get an absolute estimate of the size-specific, predaceous component of the northern squawfish population in the limnetic zone of reservoirs.

Eabitat

Three indirect habitat indices were implemented, based on -- physical habitat, optimum thermal habitat, and the morphoedaphic index (MEI). The assumption of the index based on amount of spatial habitat (length, area, or volume: Table A-11) in various reservoirs compared to John Day Reservoir was that predator abundance is homogeneous throughout the system. This assumption is similar to that of the System Planning Model (SPM) which uses a constant in-reservoir mortality rate per river mile. This assumption is obviously not valid, based on available relative abundance and CPUE data throughout the system (Tables A-9 and A-10). The point of this exercise, however, was that amount of physical habitat should be taken into consideration in a predator abundance index.

The thermal index (Table A-12) goes one step further by refining the total volume of habitat available down to the amount of spatio-temporal species-specific optimum thermal habitat available. Christie and Regier (1988) found strong power relationships between optimum thermal habitat measure and sustained commercial fisheries yield of four species in 21 large north-temperate lakes. We think this method has some promise in the Columbia River reservoirs since the daily temperature data are available from each dam in the system, and one can make predictions of predator interactions from the relative habitat available to each species of predator. In order to make this index more realistic, however, it will be necessary to develop predator-specific relations between temperature and growth from samples of fish inhabiting the Columbia River. Use of hypothetical optimum thermal range from off-site literature values is sufficient for a demonstration of the method, but is probably not accurate. For example, these preliminary results would indicate that smallmouth bass and channel catfish would have little if any optimum thermal habitat, but their populations in the river appear to be doing quite well.

The ME1 is a well established method to predict order of magnitude potential fish productivity based on water salinity (TDS) and mean reservoir depth (Ryder et al. 1974). In fisheries management, timeliness is often more important than precision, and the proper application of the ME1 provides a rapid first-approximation answer to fisheries yield problems (Ryder 1982). After comparing several indirect indices, Leach *et al. (1987)* found that the ***"best overall empirically derived estimator of potential fish yield for the Great Lakes was the morphoedaphic index".*** Based on an evaluation of data from 290 reservoirs in the United States, Jenkins (1982) concluded that the ME1 can be used to predict both fish harvest and standing crop in reservoirs, and it is of practical utility to reservoir managers who must make decisions on the basis of minimal field data. It would probably be useful to implement this index in the Columbia River as an order of magnitude estimator of the potential total fish biomass, but the results alone would probably not be sufficient for predation management purposes. We were unable to obtain any TDS data and only limited data on conductivity (a surrogate measure), however, these preliminary data suggest substantial variation in TDS within the Columbia River System (Table A-13). In order to implement the MEI, average TDS during the growing season (April to September) would have to measured in each reservoir and reach in the system.

Additionally, literature was reviewed on other habitat models, e.g., the HEP approach which utilizes HSI models. There are three types of HSI fish models (Terre11 *et al. 1982):* (1) regression, (2) descriptive, and (3) mechanistic. Regression models represent an empirical approach for predicting fish standing crop or harvest from environmental variables. Regression models developed by the National Reservoir Research Program have been used for reservoir fisheries planning: e.g., HSI models have been developed for 16 warmwater species (Aggus and Morais 1979) and 12 coolwater species (Aggus and Bivin 1982). Descriptive (word) models consist of environmental variables that are judged most important to the species, (e.g., McMahon and Terre11 1982). Specific cause-effect relationships are not hypothesized in descriptive models, and habitat ratings are based on presence or absence of optimum values of selected variables. Mechanistic HSI models are constructed as a hierarchical set of hypotheses about species-habitat relationships (Terre11 et *al. 1982).* The hypotheses are developed in four stages. First, variables are chosen that represent key habitat features known to affect the growth, survival, abundance, standing crop, distribution, or other measure of habitat quality for the species. Second, the relationship between each habitat variable and carrying capacity (= habitat suitability) for the species is translated into a graphic hypothesis (= suitability index). Third, habitat variables are aggregated via mathematical expressions into the model components (e.g., food, cover, water quality, and reproduction). Fourth, the model components are aggregated into a species HSI equation (with assumptions of variable interactions) that yields a single numerical description (index) of the habitat suitability. If a mechanistic HSI model were developed for northern squawfish in the mainstem Columbia River, it could be used to compare the potential productivity or carrying capacity of various reservoirs for the species.

## Relations between predation and environmental variables

### Modeling ecological relations

We have worked with Dr. James Petersen (USFWS) and Dr. L.J. (Sam) Bledsoe to refine predation dynamics in the Columbia River Ecology Model (CREM). We have recently subcontracted with Dr. Bledsoe to initiate modification of CREM to incorporate sub-models necessary to simulate the effects of predator removal on salmonid mortality.

### Year class strength

We summarized available information on the potential interaction between northern squawfish and walleye year class strength. Data on interactions are limited, and further simulation studies in conjunction with Dr. Bledsoe's CREM development will be required to further define compensatory regulation mechanisms.

## Field Sampling

Species and size composition, CPUE, and age determinations of northern squawfish and walleyes were determined from field sampling in John Day Reservoir in 1989. It was not possible to determine year class strength from 1989 data because the amount of planned effort was limited and the numbers of fish captured were insufficient. We are currently developing a model of a known hypothetical fish population to test the sample sizes necessary to estimate year class strength, and to evaluate which of several methods results in the most accurate estimate -- given sampling design constraints. We also collected northern squawfish gonad samples this season -- in order to quantify the relation between fish size and fecundity. This size-specific fecundity relation will be analyzed in 1990, and included in our final report.

## Predator Control Fishery Development & Evaluation Plan

The goal of the "Test Fishery" is to field test three types of fisheries ,i.e., commercial-bounty, sport-bounty, and dam angling, to determine which fishery is most effective at specific areas and sites. An additional benefit of this project will be to expedite the implementation of comprehensive predator control. Implementation of system-wide control fisheries will be directed to specific reservoirs and sites by the relative magnitude of predation as determined by the Predation Index. We are defining a "Predator Control Program" as an integrated approach of predation assessment (indexing), directed predator removal, evaluation of the direct effect on the target species (i.e., northern squawfish) and of intra- and inter-specific compensatory mechanisms, simulation of the effects on salmonid populations, adaptive management, and beneficial use of all fishery resources.

The goal of evaluation is to measure the effects of predator (northern squawfish) removal programs in terms of an achievable criterion to judge success or failure. The two main components of the evaluation program are (1) biological, and (2) socioeconomic. Extensive northern squawfish control projects were implemented in the mid-1950's and early 1960's (USFWS 1957; LeMier and Mathews 1962). We believe there were several reasons these predator control efforts failed, and we should learn from the experience: (1) only localized removal was attempted, (2) significance of system-wide predation was not measured, (3) there was no strategic planning for fishery implementation, (4) there was no way to judge efficacy of control efforts, (5) there was no consideration of fishery economics nor plan for self-sustained fisheries, and (6) the project lost agency support.

We believe biological evaluation should be designed in the context of fish community structure and function. Fish community structure is defined by species composition (presence / absence), diversity (number of species), and relative abundance (percent by species) of fish populations: and the size composition of each population. Fish community function is the hierarchial organization of fish populations based on fish size, behavioral interactions, and habitat interactions. Functional factors affecting fish community structure include: (1) species richness as a function of lake area and habitat characteristics; (2) loss of top predator (e.g., northern squawfish); (3) direct predation or indirect competition effects: (4) energy transfer and storage as a function of body size: (5) introduction of exotic species (e.g., walleyes, smallmouth bass, and channel catfish); (6) stability as a function of community complexity; (7) dominance shifts as a function of habitat and climatic purturbations (e.g., the hydropower system); (8) coexistence of species as a function of complementary form and behavior; (9) resource partitioning as a function of morphological differentiation: (10) growth rates, survival rates, and age of maturity as a function of ontogenetic niche shifts and species interactions; (11) food availability as a function of efficiency of resource sharing; and (12) community stability regulated by prey switching (Evans et al. 1987).

None of the previous northern squawfish removal experiments monitored the dynamics of the predator populations nor the ecology of the fish community during and after removal. Based on observations of northern squawfish in John Day Reservoir, Rieman and Beamesderfer (1988) speculated that strong compensation in reproductive potential is unlikely if numbers were reduced because growth was slow, natural mortality on adults was low, and fecundity was one or two orders of magnitude less than "resilient" (Cushing 1971) fish stocks. It is not known, however, how mortality rates of juveniles, and consumption rates (and associated growth rates) of various age classes of northern squawfish would respond if the larger more predaceous segment of the population were removed. Furthermore, the impact of northern squawfish removals on the population dynamics of other predator species cannot be predicted with confidence. Campbell (1979) and Larkin (1979) reasoned that if one predator species is removed, other predators would compensate to some degree for the reduction. Changes in the functional response of predators can also compensate for their reduction in numbers (Peterman and Gatto 1978).

Few studies have examined the persistence of predator removal programs. Moyle et al. (1983) suggested that a population of Sacramento squawfish recovered within 10 years of removals in a California river. Forester and Ricker (1941) concluded that northern squawfish would have to "be kept always at a low level by continued persecution". Investigators evaluating localized control efforts near Columbia River hatcheries concluded that effects would not be persistent because of a influx of fish from other areas (Zimmer 1953), i.e., a "numerical response". The necessity of sustained exploitation was one factor in the rationale to examine the feasibility of using fisheries (commercial, bounty, or recreational) to control northern squawfish populations. We are currently developing a comprehensive plan to evaluate the effects of predator removal using fisheries. A preliminary evaluation strategy will be tested in the 1990 Test Fishery in John Day Reservoir and specific projects.

## Summary and Conclusions

(1) Literature reviews were conducted on fish population abundance indices (direct and indirect), habitat indices, and factors regulating fish populations -- including year class strength determinants and compensatory mechanisms.

(2) Available information on northern squawfish population abundance and catch per unit effort (CPUE) in the Columbia River System was summarized.

(3) Several different approaches would be possible to index predator (northern squawfish) abundance in Columbia River reservoirs, including: expert consensus, catch per unit effort (CPUE), mark-recapture experiments, hydroacoustics, and various potential fish productivity models based on habitat.

(4) Based on a review of the literature and our previous experience in sampling Columbia River reservoirs, CPUE of gill nets and electroshockers appears to be the most feasible approach to directly index northern squawfish abundance; we are currently evaluating a method to adjust a CPUE relative abundance index for variable catchability; sampling design considerations and sample size determinations for a CPUE index will be evaluated in the Final Report:

(5) Specific Predator Abundance Index methods were tested with available data for demonstration, including: a Predation Questionnaire, predator abundance based on total physical habitat (length, area, volume) relative to John Day Reservoir, optimum thermal habitat, and morphoedaphic index (MEI).

(6) The Predation Questionnaire results reflect the opinion and perception that the relative predation problem is worst in lower Columbia River reservoirs (Bonneville Dam Tailrace to McNary Reservoir) -- but it is based on individuals' interpretations of incomplete information. Thus the Predation Questionnaire may be helpful in planning the implementation of the predation indexing and test fishery, but the results **are <u>not</u> true** fact.

(7) If one assumes northern squawfish numbers are homogeneously distributed throughout the Columbia River System and the density is equal to that estimated in John Day Reservoir (-85,000) -- the total abundance could vary from about 0.5 to 1.0 million depending on whether length, area, or volume is used as the measure of physical (spatial) habitat. The assumption that predator abundance is homogeneous throughout the system is obviously **<u>not</u>** valid -- based on the review of available relative abundance and CPUE data. The amount of physical habitat, however, is one factor that should be taken into consideration in a constructing a predator abundance index.

(8) An optimum thermal habitat index would be feasible to implement in the Columbia River Basin because extensive environmental temperature data are available from all the mainstem dams. Test-implementation of this index demonstrated that there is substantial variation in water temperature among the reservoirs in the system. In order to effectively implement this index, however, refined relationships for optimum temperature (e.g., growth as a function of temperature) would have to be developed for each of the major fish predators (i.e., northern squawfish, walleyes, smallmouth bass, and channel catfish) sampled from the Columbia River.

(9) The morphoedaphic index (MEI) has been shown to be a good method to grossly predict potential fish productivity in various waters. A test-implementation of this method showed substantial variation in potential fish productivity in various reservoirs throughout the Columbia River System. It would be feasible to implement the ME1 in the Columbia River reservoirs at a low cost -- as an independent comparison of a primary method (e.g., CPUE) .

(10) The Habitat Evaluation Procedure (REP) incorporates Habitat Suitability Indices (HSI) that can be used to compare the carrying

capacity (i.e., potential fish productivity) of various reservoirs for a given fish species. Mechanistic HSI models are built on the best available information on site-specific functional relationships between important environmental variables and the carrying capacity for a given species. Off-site HSI models have been developed for the major fish predators in the Columbia River -- with the exception of northern squawfish. It would be valuable to develop a HSI model for northern squawfish in the mainstem Columbia River: and to modify the existing HSI models for walleyes, smallmouth bass, and channel catfish to make them site-specific.

(11) During April through August 1989, monthly sampling was conducted at four areas in John Day Reservoir using bottom-set gill nets: additionally hook and line angling was conducted at McNary Dam tailrace. This field sampling resulted in the following information:

(a) Standardized (1-3 hour) bottom-set gill nets (n= 159) captured 89 northern squawfish (CPUE= 0.27 fish $\cdot$ $h^{-1}$) and 6 walleyes (CPUE= 0.02 fish $\cdot$ $h^{-1}$);

(b) Incidental (non-target species) catches from all (n=165) bottom gill net sets were: 503 bridgelip and largescale suckers: 75 American shad; 54 white sturgeon ; 48 bullhead and channel catfish: 16 chiselmouth; 9 smallmouth bass: 4 coho and sockeye salmon: 4 carp: 3 yellow perch: and 2 white and black crappies.

(c) Hook and line angling at McNary Dam tailrace (n= 6) captured 443 northern squawfish (CPUE= 12.6 fish $\cdot$ $h^{-1}$), with no incidental catch of other species;

(d) There was no significant ($p > 0.05$) difference in northern squawfish CPUE from bottom-set gill nets by sampling time (early versus late) or reservoir location (upper versus lower);

(e) Length of northern squawfish varied significantly ($p < 0.05$) by: time (early versus late); John Day Reservoir area (upper versus lower) ; John Day pool versus McNary Dam tailrace; and sex (females versus males);

(f) Size distributions (length and weight) and age distributions are presented for northern squawfish and walleyes sampled in bottom-set gill nets, and the length distribution of northern squawfish captured in dam angling is documented:

(g) Insufficient numbers of northern squawfish and walleyes were captured in bottom-set gill nets during 1989 to make back-calculations of year class strength.

(12) Several methods for analyzing year class strength were reviewed and summarized; a sensitivity analysis of the various methods will be conducted for the Final Report in order to evaluate sampling design and sample size requirements.

(13) A preliminary plan to implement predation indexing and test fisheries in John Day Reservoir and selected hydroelectric projects is presented. Biological and economic evaluation of the efficacy of predator removal fisheries is a critical element of the proposed Predator Control Program: evaluation will include field monitoring and simulation modeling.

## REFERENCES

Aggus, L.R., and W.M. Bivin. 1982. Habitat suitability index models: regression models based on the harvest of coolwater and coldwater fishes in reservoirs. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.25. Fort Collins, Colorado. 120 pp.

Aggus, L.R., and D.I. Morais. 1979. Habitat suitability index equations for reservoirs based on standing crop of fish. National Reservoir Research Program Report to U.S. Fish and Wildlife Service Habitat Evaluation Project. Fort Collins, Colorado. 120 pp.

Armour, C.L., R.J. Fisher, and J.W. Terrell. 1984. Comparison of the use of the Habitat Evaluation Procedures (HEP) and the Instream Flow Incremental Methodology (IFIM) in aquatic analyses. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-84/11 , Washington, D.C. 30 pp.

Bagenal, T.B., and F.W. Tesch. 1978. Age and Growth. Pages 101-136 in T. Bagenal editor. Methods for assessment of fish production in fresh waters. Blackwell Scientific Publications, Oxford, England.

Bannerot, S.P., and C.B. Austin. 1983. Using frequency distribution of catch per unit effort to measure fish-stock abundance. Transactions of the American Fisheries Society 112:608-617.

Beamesderfer, R.C., and B.E. Rieman. 1988a. Predation by resident fish on juvenile salmonids in a mainstem Columbia reservoir: Part III. Abundance and distribution of northern squawfish, walleye, and smallmouth bass. Pages 211-248 *in* T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE- AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Beamesderfer, R.C., and B.E. Rieman. 1988b. Size selectivity and bias in estimates of population parameters of smallmouth bass, walleye, and northern squawfish in a Columbia River reservoir. North American Journal of Fisheries Management 8:505-510.

Beamesderfer, R.C., B.E. Reiman, J.C. Elliott, A.A. Nigro, and D.L. Ward. 1987. Distribution, abundance, and population dynamics of northern squawfish, walleye, smallmouth bass, and channel catfish in John Day Reservoir, 1986. Annual Report to Bonneville Power Administration (Contract DE-A179-82BP35097), Portland, Oregon.

Beamish, R.J. and D.A. Fourner. 1981. A method for comparing the precision of a set of age determinations. Canadian Journal of Fisheries and Aquatic Sciences. 38: 982-983.

Beckman, L.G., J.F. Novotny, W.R. Persons, and T. T. Terrell. 1985. Assessment of the fisheries and limnology in Lake F.D.Roosevelt, 1980-1983. U.S. Fish and Wildlife Service, Willard Substation, Seattle National Fishery Research Center. Contract No. WPRS-0-07-10-X026 FWS-14-06-009-904 to Bureau of Reclamation. 168 pp.

Bell, M.C., Z.E. Parkhurst, R.G. Porter, and M. Stevens. 1976. Effects of power peaking on survival of juvenile fish at lower Columbia and Snake River dams. Contract No. DACW57-75-C-0173, U.S. Army Corps of Engineers, Portland, Oregon.

Bennett, D.H., P.M. Bratovich, W. Knox, D. Palmer, and H. Hansel. 1983. Status of warmwater fishery and potential for improving warmwater fish habitat in the lower Snake River reservoirs. Completion report No. DACW68-79-C0057 by the University of Idaho to U.S. Army Corps of Engineers, Walla Walla, Washington.

Bennett, D.H., L.K. Dunsmoor, and J.A. Chandler. 1988. Fish and benthic community abundance at proposed in-water disposal sites, Lower Granite Reservoir. Final Report by the University of Idaho to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Bledsoe, L.J. 1989. Columbia River Ecosystem Model -- Modeling approach for evaluation of control of northern squawfish populations using fisheries exploitation. Statement of Work, Subcontract to Project 82-012, Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Oregon Department of Fish and Wildlife, Contract Number DE-AI79-88BP92122 with Bonneville Power Administration, Portland, Oregon.

Brown, L.R., and P.B. Moyle. 1981. The impact of squawfish on salmonid populations: a review. North American Journal of Fisheries Management 1:104-111.

Burnham, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.C. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph 5. Bethesda, Maryland.

Burczunski, J., and R. Johnson. 1986. Application of dual-beam survey techniques to limnetic populations of juvenile sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 43:1776-1778.

Campbell, P.K. 1979. Predation principles in large rivers: a review. Pages 181-192 in H. Clepper, editor. Predator- prey systems in fisheries management. Sport Fishing Institute, Washington, D.C.

Chang, W.Y.B. 1982. A Statistical method for evaluating the reproducibility of age determination. Candian Journal of Fisheries and Aquatic Sciences 39:1208-1210.

Cheng, C.W. 1987. Compensatory mechanisms in fish populations: literature reviews. Volume 3: a critical review of mathematical models for fish compensation mechanisms. Final Report EA-5200, Volume 3, Research Project 1633-6. Prepared for Electric Power Research Institute, Palo Alto, California.

Christie, G.C., and A.A. Regier. 1988. Measures of optimal thermal habitat and their relationship to yields of four commercial fish species. Canadian Journal of Fisheries and Aquatic Sciences 45:301-314.

Christie, W.J., and G.R. Spangler, editors. 1987. International symposium on stocks assessment and yield prediction. Canadian Journal of Fisheries and Aquatic Sciences 44: Supplement Number 2.

Clark, S.M., and G.R. Snyder. 1970. Limnological study of lower Columbia River, 1967-68. U.S. Fish and Wildlife Service, Special Scientific Report -- Fisheries Number 610:1-14.

Cushing, D.H. 1971. The dependence of recruitment on parent stock in different groups of fishes. Journal du Conseil, Conseil International pour l'Exploration de la Mer 164:142- 155.

Dell, M.B., M.W. Erho, and B.D. Leman. 1975. Occurrence of gas bubble disease symptoms on fish in mid-Columbia River reservoirs. Public Utility Districts of Grant, Douglas and Chelan Counties, Ephrata, Washington, USA.

Dupont, W.D. 1983. A Stochastic catch-effort method for estimating animal abundance. Biometrics 39:1021-1033.

Edwards, E.A., G. Gebhart, and O.E. Maughan. 1983. Habitat suitability information: smallmouth bass. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.36, Washington, D.C.

Edwards, E.A., and K. Twomey. 1982. Habitat suitability index models: common carp. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-84/11 , Washington, D.C.

El-Zarka, S.E. 1959. Fluctuations in the population of yellow perch, *Perca fluvescens* (Mitchill) in Saginaw Bay, Lake Huron. U.S. Fish and Wildlife Service Fishery Bulletin 151.

Emery, L., and R. Wydowski. 1987. Marking and tagging of aquatic animals: an indexed bibliography. U.S. Fish and Wildlife Service, Resource Publication 165:1-57.

Erickson, A.W., Q.J. Stober, J.J. Brueggeman, and R.L. Knight. 1977. An assessment of the impact of the wildlife and fisheries resources of Rufus Woods Reservoir expected from raising the Chief Joseph Dam from 946 to 956 ft. m.s.l. Final Report by University of Washington to Colville Tribal Council, and the Seattle District U.S. Army Corps of Engineers.

Evans, D.O., B.A. Henderson, N.J. Bax, T.R. Marshall, R.T. Oglesby, and W.J. Christie. 1987. Concepts and methods of community ecology applied to freshwater fisheries management. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2): 471-485.

Faler, M.P., L.M. Miller, and K.I. Welke. 1987. Effects of variation in flow on distributions of northern squawfish in the Columbia River below McNary Dam. North American Journal of Fisheries Management 8:30-35.

Fickeisen, D.H., D.D. Dauble, and D.A. Neitzel. 1989. Proceedings on the predator-prey modeling workshop. Friday Harbor, Washington. May 16-19, 1989. Pacific Northwest Laboratory, Battelle. Contract DE-AC06-76RLO 1830 to Bonneville Power Administration, Portland, Oregon.

Foerster, R.E., and W.E. Ricker. 1941. The effect of reduction of predaceous fish on survival of young sockeye salmon at Cultus Lake. Journal of the Fisheries Research Board of Canada 5:315-336.

FPC (Fish Passage Center). 1988. Smolt monitoring program, 1987 Annual Report. Fish Passage Center, Columbia Basin Fish and Wildlife Authority, Portland, Oregon. 112p.

Fry, F.E.J. 1947. The effect of the environment on animal activity. Ontario Fisheries Research Laboratory Publication 68:1-62.

Funk, W.H., C.M. Falter, and A.J. Lingg. 1985. Limnology of an impoundment series in the lower Snake River. Contract Numbers DACW 68-75-C-0143 and 0144. Final Report to U.S. Army Corps of Engineers, Walla Walla, Washington. 141 pp t Appendices.

Gray, R.H., and D.D. Dauble. 1977. Checklist and relative abundance of fish species from the Hanford Reach of the Columbia River. Northwest Science 51:208-215.

Gray, R.H., and D.D. Dauble. 1978. Fish studies near Washington nuclear plants 1,2, and 4, March through December 1976. Washington Public Power Supply System Columbia River ecology studies, Volume 4, Battelle Pacific Northwest Laboratories, Richland, Washington, USA.

Gray, G.A., and D.W. Rondorf. 1986. Predation on juvenile salmonids in Columbia Basin Reservoirs. Pages 178-185 *in* G.E. Hall and M.J. Van Den Avyle, editors. Reservoir Fisheries Management in the 1980's. Reservoir Committee, Southern Division, American Fisheries Society. Bethesda, Maryland.

Gulland, J.A. 1964. Catch per unit effort as a measure of abundance. Rapports et Proces-Verbaux des Reunions Conseil International pour l'Exploration de la Mer 155:8-14.

Gulland, J.A. 1983. Fish stock assessment: a manual of basic methods, Volume 1. FAO/Wiley Series On Food and Agriculture. New York: John Wiley and Sons.

Hanna, S. 1990. Feasibility of commercial and bounty fisheries. Report B in A.A. Nigro, editor. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Oregon Department of Fish and Wildlife, Contract Number DE-AI79-88BP92122. 1989 Annual Report to Bonneville Power Administration, Portland, Oregon.

Hile, R. 1941. Age and growth of the rock bass, ***Ambloplites rupestris*** (Rafinesque), in Nebish Lake, Wisconsin. Transactions of the Wisconsin Academy of Sciences, Arts and Letters, vol. 33, pp. 189-337.

Hjort, R.C., B.C. Mundy, P.L. Hulett, H.W. Li, C.B. Schreck, R.A. Tubb, H.W. Horton, L.D. LaBalle, A.G. Maule, and C.E. Stainbrook. 1981. Habitat requirements for resident fishes in the reservoirs of the lower Columbia River. Completion Report No. DAC 57-79-C0067 by Oregon State University. U.S. Arny Corps of Engineers, Walla Walla, Washington, USA.

Jearld, W.E. 1983. Age determination. Pages 301-323 ***in*** L.A. Nielson and D.L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Jenkins, P.M. 1982. The morphoedaphic index and reservoir fish production. Transactions of the American Fisheries Society 111:133-140.

Jude, D.J., P.J. Mansfield, P.J. Schneeberger, and J.A. Wojcik. 1987. Compensatory mechanisms in fish populations: literature reviews. Volume 2: compensation in fish populations subject to catostrophic impact. Final Report EA-5200, Volume 2, Research Project 1633-6. Prepared for Electric Power Research Institute, Palo Alto, California.

Lagler, K.F. 1978. Capture, sampling and examination of fishes. Pages 7-47 in T. Bagenal, editor. Methods for assessment of fish production in fresh waters, 3rd edition. Blackwell Scientific Publications, London.

Larkin, P.A. 1979. Predator-prey relations in fishes: an overview of the theory. Pages 13-20 ***in*** H.C. Clepper, editor. Predator-prey systems in fisheries management. Sport Fishing Institute, Washington, D.C.

Laumeyer, P. 1972. Gill net survey -- reservoir behind Chief Joseph Dam. U.S. Fish and Wildlife Service (Unpublished), Portland, Oregon, USA.

Layher, W.G., and O.E. Maughan. 1984. Analysis and refinement of habitat suitability index models for eight warm-water fish species. Pages 182-250 in J.W. Terrell, editor. Proceedings of a workshop on fish habitat suitability index models. U.S. Fish and Wildlife Service Biological Report 85(6), Washington, D.C., USA

Layher, W.G., and O.E. Maughan. 1985. Relations between habitat variables and channel catfish populations in prairie streams. Transactions of the American Fisheries Society 114:771-781.

Leach, J.H., L.M. Dickie, B.J. Shuter, U. Borgeman, J. Hyman, and W. Lysack. 1987. A Review of the methods for prediction of potential fish production with application to the Great Lakes and Lake Winnipeg. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2): 471-485.

LeMier, E.H., and S.B. Mathews. 1962. Report on the developmental study of techniques for scrapfish control. Washington Department of Fisheries. Contract Numbers 14-17-0001-373 and 14-17-0001-538 to the Bureau of Commercial Fisheries and the U.S. Fish and Wildlife Service. 60 pp.

Lindland, R.L. 1973. Squawfish control in Cascade Reservoir, Federal Aid Project F-53-R-8 Job 2a, Idaho Fish and Game Department, Boise, Idaho, USA.

Long, C.W. 1968. Diel movement and vertical distribution of juvenile anadromous fish in turbine intakes. U.S. Fish and Wildlife Service Fishery Bulletin 66: 599-609.

Mathews, S.B., T. Iverson, R.W. Tyler, and G. Ruggeronne. 1990. Evaluation of harvesting technology for potential northern squawfish commercial fisheries in Columbia River reservoirs. Report C in A.A. Nigro, editor. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Oregon Department of Fish and Wildlife, Contract Number DE-AI79-88BP92122. 1989 Annual Report to Bonneville Power Administration, Portland, Oregon.

McClendon, D.D., and C.F. Rabeni. 1987. Physical and biological variables useful for predicting population characteristics of smallmouth bass and rock bass in an Ozark stream. North American Journal of Fisheries Management 7:46-56.

McGee, J. 1979. Resident fish survey of Wells Reservoir, 1979. Public Utility District No. 1 of Douglas County, East Wenatchee, Washington, USA.

McMahon, T.E., and J.W. Terrell. 1982. Habitat suitability index models: channel catfish. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.2, Washington, D.C.

McMahon, T.E., J.W. Terrell, and P.C. Nelson. 1984. Habitat suitability information: walleye. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.56, Washington, D.C.

Moyle, P.B., B. Vondracek, and G.D. Grossman. 1983. Responses of fish populations in the North Fork of the Feather River, California to treatments with fish toxicants. North American Journal of Fisheries Management 3:48-60.

Mullan, J.W., M.B. Dell, S.G. Hays, and J.A. McGee. 1986. Some factors affecting fish production in the mid-Columbia River, 1934-1983. U.S. Fish and Wildlife Report No. FRI/FAO-86-15: l-69.

Nelson, W.R. 1981. Population dynamics of fish populations in McNary Reservoir. Interim Progress Report 1980-81, U.S. Fish and Wildlife Service, Seattle, Washington, USA.

Nigro, A.A., C.F. Willis, R.C. Beamesderfer, J.C. Elliott, and B.L. Uremovich. 1985. Abundance and distribution of walleye, northern squawfish, and smallmouth bass in John Day Reservoir and tailrace, 1983. Report (Contract DE-A179-82BP35097) to Bonneville Power Administration, Portland, Oregon.

NPPC (Northwest Power Planning Council). 1987. Columbia River Basin Fish and Wildlife Program. Adopted November 15, 1982, ammended October 10, 1984, and February 11,1987. Northwest Power Planning Council, Portland, OR.

Overton, W.S. 1965. A modification of the Schnabel estimator to account for removal of animals from the population. Journal of Wildlife Management 29:392-395.

Paloheimo, J.E., and L.M. Dickie. 1964. Abundance and fishing success. Rapports et Proces-Verbaux des Reunions Conseil International pour l'Exploration de la Mer 155:152-163.

Paragamian, V.L. 1981. Some habitat characteristics that affect abundance and winter survival of smallmouth bass in Maquoketa River, Iowa. Pages 45-53 in L.A. Krumholz, editor. Warmwater streams symposium. American Fisheries Society, Southern Division, Bethesda, Maryland.

Pauley, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. int. Explor. Mer. 39:175-192.

Peterman, R.M., and M. Gatto. 1978. Estimation of functional responses of predators on juvenile salmon. Journal of the Fisheries Research Board of Canada 35:797-808.

Poe, T.P., and W.R., Nelson. 1988. Magnitude and dynamics of predator-caused mortality on healthy juvenile salmonids in Columbia and Snake River reservoirs. Statement of Work. (Contract No. A179-82BP34796). Bonneville Power Administration, Portland Oregon.

Poe, T.P., and B.E. Rieman, editors. 1988. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Poe, T.P., P.T. Lofy, S.D. Duke, A.A. Nigro, and B.E. Rieman. 1988. Feasibility of reducing or controlling predation induced mortality of juvenile salmonids in Columbia River reservoirs. Pages 153-173 in T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I --Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Precht, H., J. Christophersen, H. Hensel, and W. Larcher. 1973. Temperature and life. Springer-Verlag, New York, New York. 779 pp.

Raymond, H.L. 1988. Effects of hydroelectric development and fisheries enhancement on spring and summer chinook salmon and steelhead in the Columbia River basin. North American Journal of Fisheries Management 8:1-24.

Richards, L.J., and J.T. Schnute. 1986. An experimental and statistical approach to the question: Is CPUE an index of abundance? Canadian Journal of Fisheries and Aquatic Sciences. 43:1214-1227.

Ricker, W.E. 1940. Relation of “catch-per-unit-effort” to abundance and rate of exploitation. Journal of Fisheries Research Board of Canada. 5:43-70.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Rieman, B.E., and R.C. Beamesderfer. 1988. Population dynamics of northern squawfish and potential predation on juvenile salmonids in a Columbia River reservoir. Pages 274-306. *in* T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79- 82BP35097) Bonneville Power Administration, Portland, Oregon.

Rieman, B.E., R.C. Beamesderfer, S. Vigg, and T.P. Poe. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia reservoir Part IV: Estimated total loss and mortality of juvenile salmonids to northern squawfish, walleye, and smallmouth bass. Pages 249-273 *in* T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Ryder, R.A. 1965. A method for estimating the potential fish production of north temperate lakes. Transactions of the American Fisheries Society 94:214-218.

Ryder, R.A. 1982. The morphoedaphic index -- use, abuse, and fundamental concepts. Transactions of the American Fisheries Society 111:154-164.

Ryder, R.A., S.R. Kerr, K.H. Loftus, and H.A. Regier. 1974. The mophoedaphic index, a fish yield estimator -- review and evaluation. Journal of the Fisheries Research Board of Canada 31:663-688.

Saila, S.B., X. Chen, K. Erzini, and B. Martin. 1987. Compensatory mechanisms in fish populations: literature reviews. Volume 1: critical evaluation of case histories of fish populations experiencing chronic exploitation or impact. Final Report EA-5200, Volume 1, Research Project 1633-6. Prepared for Electric Power Research Institute, Palo Alto, California.

Schlesinger, D.A., and Ii. Regier. 1983. Relationship between environmental temperature and yields of subartic and temperate zone fish species. Canadian Journal of Fsheries and Aquatic Sciences 40:1829-1837.

Seber, G.A.F. 1982. Estimation of animal abundance and related parameters. Macmillan Publishing Company, New York, 2nd Edition, 654 pp.

Sims, C.W., W.W. Bently, and R.C. Johnson. 1977. Effects of power peaking operations on juvenile salmon and steelhead trout migrations -- progress 1976. Final Report to U.S. Army Corps of Engineers, Contract DACW68- 77-C-0025. Coastal Zone and Estuarine Studies Division, Northwest and Alaska Fisheries Center, National Marine Fisheries Center, National Marine Fisheries Service, Seattle, Washington.

Sims, C.W., W.W. Bently, and R.C. Johnson. 1978. Effects of power peaking operations on juvenile salmon and steelhead trout migrations -- progress 1977. Final Report to U.S. Army Corps of Engineers, Contract DACW68- 77-C-0025. Coastal Zone and Estuarine Studies Division, Northwest and Alaska Fisheries Center, National Marine Fisheries Center, National Marine Fisheries Service, Seattle, Washington.

Stober, Q.J., M.E. Kopache, and T.H. Jagielo. 1981. The limnology of Lake Roosevelt, 1980. Final Report, University of Washington, Fisheries Research Institute, FRI-UW-8106. 116 pp.

Stuber, R.J., G. Gebhart, and O.E. Maughan. 1982. Habitat suitability index models: largemouth bass. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.16, Washington, D.C.

Terrell, J.W., editor. 1984. Proceedings of a workshop on fish habitat suitability index models. U.S. Fish and Wildlife Service, Biological Report 85 (6).

Terrell, J.W., T.E. McMahon, P.D. Inskip, R.F. Raleigh, and K.L. Williamson. 1982. Habitat suitability index models: Appendix A. Guidelines for riverine and lacustrine applications of fish HSI models with the habitat evaluation procedures. U.S. Fish and Wildlife Service, FWS/OBS-82/10.A.

Thompson, R.B. 1959. Food of the squawfish ***Ptychocheilus oregoneosis*** (Richardson) of the lower Columbia River. U.S. Fish and Wildlife Service, Fishery Bulletin 158:43- 58.

Thompson, R.B., and R.E. Morgan. 1959. Appraisal of the losses of juvenile salmonids to predators at Bonneville Dam. Pacific Salmon Investigations, U.S. Fish and Wildlife Service, Seattle, Washington.

Thorne, R.E. 1983. Assessment of population abundance by hydroacoustics. Biological Oceanography 2:254-261.

Thorton, K.W., and A.S. Lessem. 1978. A temperature algorithm for modifying biological rates. Transactions of the American Fisheries Society 107: 284-287.

Uremovich, B.L., S.P. Cramer, C.F. Willis, and C.O. Junge. 1980. Passage of juvenile salmonids through the ice-trash sluiceway and squawfish predation at Bonneville Dam, 1980. Oregon Department of Fish and Wildlife, Fish Research Project DACW57-78-C0058, Annual Progress Report to U.S. Army Corps of Engineers, Portland, Oregon.

USFWS (U.S. Fish and Wildlife Service). 1957. Progress report: squawfish predation study. USFWS, Office of the Regional Director, Portland, Oregon. 23 p.

USFWS (U.S. Fish and Wildlife Service). 1980a. Habitat as a basis for environmental assessment, 101 ESM. Division of Ecological Services, Washington, D.C.

USFWS (U.S. Fish and Wildlife Service). 1980b. Habitat evaluation procedures (HEP). Division of Ecological Services, Washington, D.C.

USFWS (U.S. Fish and Wildlife Service). 1981. Standards for the development of habitat suitability index models. 103 ESM. Division of Ecological Services, Washington, D.C.

Vigg, S. 1988. Functional response of northern squawfish predation to salmonid prey density in McNary tailrace, Columbia River. Pages 174-207 ***in*** T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I --Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Vigg, S., R.C. Beamesderfer, and C.C. Burley. In Preparation. A fish population relative abundance estimator based on size-stratified CPUE and vulnerability. Canadian Journal of Fisheries and Aquatic Sciences.

Vigg, S., and **C.C. Burley.** 1990. Temperature dependent maximum daily consumption of juvenile salmonids by northern squawfish ***(Ptychocheilus oregonensis)*** from the Columbia River. (In Review).

Vigg, S., T.P. Poe, L.A. Prendergast, and H.C. Hansel. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia River reservoir: Part II. Consumption rates of northern squawfish, walleye, smallmouth bass, and channel catfish. Pages 56-115 *in* T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE- AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Vondracek, B., S.R. Hanson, and P.B. Moyle. 1989. Sacramento squawfish predation below a diversion dam on the Sacramento River. (In Review).

White, G.C., D.R. Anderson, K.P. Burnham, and D.L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory, LA-8787-NERP, Los Alamos, New Mexico.

Zimmer, P.D. 1953. Observations on hatchery releases and squawfish predation in Little White Salmon River in spring of 1953. Mimeo Report, U.S. Fish and Wildlife Service, Portland, Oregon.

Zuboy, J.R. 1981. A new tool for fishery managers: The Delphi Technique. North American Journal of Fisheries Management 1:55-59.

APPENDICES

APPENDIX A-1.1. Objectives of the Predator-Prey Project 82-012 “Developing a Predation Index and Evaluating Ways to Reduce Juvenile Salmonid Losses to Predation in the Columbia River Basin”, Report A: Oregon Department of Fish and Wildlife: and detailed objectives of three subcontractors: Report B: Oregon State University, Agricultural and Resource Economics; Report C: University of Washington, Fisheries Research Institute: and Bledsoe (1989): University of Washington, Center for Quantitative Science.

Report A: OREGON DEPARTMENT OF FISH AND WILDLIFE

Objectives: "Developing a Predation Index and Evaluating Ways to Reduce Juvenile Salmonid Losses to Predation in the Columbia River Basin"

Objective 1. Develop an index that can be used to estimate predation losses of smolts in various reservoirs throughout the Columbia River basin.

Task 1.1 Develop an index approach to estimate predator abundance.

Subtask 1.11 Evaluate the utility of CPUE as an index of abundance.

Subtask 1.12 Evaluate the feasibility of estimating potential predator abundance by measuring critical habitat.

Task 1.2 Assist FWS with the development of an index approach to estimate predator consumption rates.

Task 1.3 Describe the process for estimating smolt losses based on indices.

Objective 2. Describe the relationships among predator-caused mortality of smolts and physical and biological variables.

Task 2.1 Assist FWS with refinement and expansion of the predator consumption component of the John Day Reservoir predation model.

Task 2.2 Determine how changes in abundance of walleye affects abundance of northern squawfish.

Task 2.3 Reevaluate potential relationships among physical and biological variables and predator-caused mortality based on refinements of consumption model.

Task 2.4 Assist FWS with development of a strategy to incorporate a predation model(s) into a system-wide model(s) of smolt mortality or survival.

Objective 3. Examine the feasibility of developing bounty, commercial or recreational fisheries on northern squawfish.

Task 3.1 Review literature and consult with peers to identify and evaluate applicability of similar work performed elsewhere on development of bounty, commercial, and recreational fisheries on unutilized fish species.

Task 3.2 Determine the feasibility of developing bounty and commercial fisheries for northern squawfish as an alternative to other forms of predator control.

Task 3.3 Determine the feasibility of conducting a "squawfish derby".

Objective 4. iupgraded from Task 3.4} Develop an approach to evaluate the success of efforts to reduce predation by exploiting northern squawfish.

Report B: OREGON STATE UNIVERSITY, AGRICULTURE AND RESOURCE ECONOHICS

Objectives specified in a Cooperative Agreement between ODFW and OSU: "Feasibility of Commercial and Bounty Fisheries for Northern Squawfish"

Objective 1. Determine the feasibility of developing bounty and commercial fisheries for northern squawfish (*Ptychocheilus oregonensis*) as an alternative to other forms of predator control.

Task 1.1 Review fisheries and economics literature and consult with peers to identify and evaluate applicability of related work on development of bounty and commercial fisheries on unutilized or underutilized species.

Task 1.2 Review the state and federal statutes and regulations governing commercial and bounty fisheries; in cooperation with ODFW, define the procedure for obtaining public review and comment and agency\tribal approval.

Task 1.3 Examine the economic feasibility of bounty and commercial fisheries on northern squawfish.

Task 1.4 Identify when and where commercial and bounty fisheries would occur: build on data gathered in Task 1.3, and the gear and harvest-related data supplied by the UW subcontract.

Task 1.5 Outline a strategy for encouraging participation by fishermen in either bounty or commercial fisheries.

Task 1.6 Develop a plan to conduct a bounty and/or commercial fishery -- using information from Tasks 1.1 to 1.5.

Task 1.7 Coordinate with state and federal agencies and Indian tribes to examine the alternatives for managing and regulating bounty and commercial fisheries.

Objective 2. Assist ODFW with an evaluation of the economic feasibility of recreational fisheries for northern squawfish.

Task 2.1 Review fisheries and economics literature relevant to development of sport and derby (tournament) fisheries on northern squawfish.

Task 2.2 Review the state and federal statutes and regulations relevant to development of sport and derby fisheries on northern squawfish in the Columbia River.

Task 2.3 Examine the economic feasibility of sport and derby fisheries on northern squawfish.

Task 2.4 Identify existing recreational fisheries on northern squawfish, as well as timing and location of potential sport and derby fisheries. As far as existing information permits, identify potential participants in both sport and derby fisheries.

Task 2.5 Outline a strategy to enccourage participation in sport or derby fisheries.

Task 2.6 Develop a plan to conduct either a sport or derby fishery -- given the information gathered in Tasks 2.1 to 2.5.

Task 2.7 Consult with agencies and/or tribes identified in Task 2.2 regarding involvement in sport or derby fisheries. This will involve meeting with representatives of the appropriate agencies/tribes.

Objective 3. Assess the feasibility of multispecies utilization of northern squawf ish, carp (*Cyprinus carpio*), and suckers (*Catostomus spp.*); carp and suckers will be added to activities under OSU Tasks 1.3-1.7.

Report C: UNIVERSITY OF WASHINGTON, FISHERIES RESEARCH INSTITUTE

Objectives specified in a Cooperative Agreement between ODFW and UW - Fisheries Research Institute: "Evaluation of Harvesting Technology for Potential Northern Squawfish Fishery in Columbia River Basin"

Objective 1. Evaluate commercial harvesting technology of various fishing methods for northern squawfish in Columbia River reservoirs.

Task 1.1 Identify feasible fishing gears, deployment methods, holding facilities, live transportation equipment.

Task 1.2 Evaluate potential effectiveness of harvesting technology.

Objective 2. Field test the effectiveness of harvesting systems selected under Task 1.2, including trap nets (e.g., Lake Erie and Merwin types), purse seines and gill nets, as well as holding and transportation systems.

Task 2.1 Implement selected fishing systems.

Task 2.2 Collect, record and analyze biological data.

Objective 3. Integration of the "Harvesting Technology" research with other components of the Project 82-012, *i.e.*, coordination to ensure research and data collection are designed to support the "Economic Feasibility" study.

Task 3.1 Coordination with Dr. Susan Hanna of Oregon State University, Corvallis, OR.

Task 3.2 Determine costs of different fishing methods.

Bledsoe (1989): UNIVERSITY OF WASBINGTON, CENTER FOR QUANTITATIVE SCIENCE

Objectives specified in a Cooperative Agreement between ODFW and UW-Center for Quantitative Science: "Columbia River Ecosystem Model (CREM) -- Modeling Approach for Evaluation of Control of Northern Squawfish Populations Using Fisheries Exploitation"

Objective 1. Modify the existing Columbia River Ecosystem Model (CREM) to include processes necessary to evaluate the effects of predator (northern squawfish) removal on the size structure and abundance of predators.

Task 1.1. Modify the CREM program to include provisions for fishery exploitation, in addition to natural mortality.

Task 1.2. Modify the CREM program to include provisions for numerical response of predators: i.e., movement of predators into areas where removed from other areas.

Task 1.3. Modify the CREM program to include provisions for size-specific removal of predators based on various selectivity curves representing different fishing gear types.

Task 1.4. Modify the CREM program to include provisions for compensatory population dynamics (e.g., recruitment, growth, mortality) of the target population (i.e., northern squawfish).

Task 1.5. Modify the CREM program to include provisions for compensatory response of other predator species (e.g., walleye, smallmouth bass, channel catfish)

Task 1.6. Modify the CREM program to include provisions for stochastic variation of input data and driving functions.

Task 1.7. Modify the CREM program to include cummulative effects of multiple years for realistic population dynamics simulations.

Task 1.8. Develop a plan for modification of the CREM program to include cummulative effects of multiple reservoirs (system-wide implementation).

Task 1.9. Modify the CREM program to include provisions for "user friendly" input data file modifications, and graphics output of the major dynamic output variables.

Objective 2. Document the ecological processes, mathematical equations, and computer (FORTRAN) programming of the revised version of CREM.

Task 2.1. Write documentation for CREM, including explanation of the conceptual model, presentation of major assumptions, definition of all variables, descriptions and graphs of the functional processes involved, printed and electronic listing of the computer program, and instructions for use.

Objective 3. Conduct systematic analyses of various predator removal scenarios, using the revised CREM to generate the simulations.

Task 3.1. Conduct simulations of various predator removal scenarios using the revised version of CREM.

Objective 4. Incorporate the products of Objectives l-4 into integrated annual and final reports.

Task 4.1. With the assistance of the contractor, write a final report in the format of a technical publication, including complete documentation, and the results, discussion, and conclusions of the analyses of simulated predator removal.

Task 4.2. With the assistance of the contractor, write a manuscript on the results of the analyses of various predator removal scenarios in the format of a scientific publication.

APPENDIX A-1.2. Summary of progress on specific objectives of the Predator-Prey Project 82-012 "Developing a Predation Index and Evaluating Ways to Reduce Juvenile Salmonid Losses to Predation in the Columbia River Basin", Oregon Department of Fish and Wildlife: and detailed objectives of two subcontractors: Oregon State University, Agricultural and Resource Economics, and University of Washington, Fisheries Research Institute.

| Component | Objective | Task | Status / Report Reference: Not Started | In Progress | Completed |
|---|---|---|---|---|---|
| ODFW (Vigg & Burley) | 1 | 1.1 | | Rpt A | |
| | | 1.2 | | Rpt A | |
| | | 1.3 | | Rpt A | |
| | 2 | 2.1 | | | Apnd A-6 |
| | | 2.2 | | | Rpt A; Apnd A-5, A-7 |
| | | 2.3 | | Rpt A; Bledsoe | |
| | | 2.4 | | | Rpt A; Fickeisen et al. (1989) |
| | 3 | 3.1 | | | Apnd B-l |
| | | 3.2 | | Apnd A-l; Rpt B | |
| | | 3.3 | | Apnd A-l: Rpt B | |
| | 4 | 13.41 | | Rpt A; Apnd A-8 | |
| OSU (Hanna) | 1 | 1.1 | | Rpt B; Apnd B-l | |
| | | 1.2 | | Rpt B | |
| | | 1.3 | | Rpt B | |
| | | 1.4 | X | | |
| | | 1.5 | X | | |
| | | 1.6 | X | | |
| | | 1.7 | X | | |
| | 2 | 2.1 | | | Rpt B; Apnd B-l |
| | | 2.2 | | Rpt B | |
| | | 2.3 | | Rpt B | |
| | | 2.4 | | Rpt B | |
| | | 2.5 | X | | |
| | | 2.6 | X | | |
| | | 2.7 | X | | |
| | 3 | 3.1 | | Rpt B; Apnd B-l | |
| | | 3.2 | | Rpt B | |
| | | 3.3 | | Rpt B | |
| | | 3.4 | X | | |
| | | 3.5 | X | | |
| | | 3.6 | X | | |
| | | 3.1 | X | | |

APPENDIX A-1.2. (continued)

| Component Objective | | Task | Not Started | In Progress | Completed |
|---|---|---|---|---|---|
| | | | Status / Report Reference | | |
| UW-FRI (Mathews) | 1 | 1.1 | | | Rpt C; Apnd C-l |
| | | 1.2 | | | Rpt C |
| | 2 | 2.1 | | Rpt C | |
| | | 2.2 | | Rpt C | |
| | 3 | 3.1 | | Rpt C | |
| | | 3.2 | | Rpt C | |

APPENDIX A-2. Selected bibliography on fish population abundance **estimates** and indices.

## I. Direct Measurement - Fish

### A. Catch per unit effort (CPUE)

Christie, W-J., J.J. Collins, G.W. Eck, C.I. Goddard, J.M. Hoenig, M. Holey, L.D. Jacobson, W. MacCallum, S.J. Nepszy, R. O'Gorman, and J. Selgeby. 1987. Meeting future information needs for Great Lakes fisheries management. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):439-447.
[STOCK ASSESSMENT, MANAGEMENT, FISHERIES, GREAT LAKES, SYNTHESIS]

Christie, W.J., C-I. Goddard, S.J. Nepszy, J.J. Collins, and W. MacCallum. 1987. Problems associated with fisheries assessment methods in the Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2) :431-438.
[STOCK ASSESSMENT, FISHERIES, GREAT LAKES, METHODS]

Bagenal, T.B. 1972. The variability of the catch from gill nets set for pike, Esox *lucius* L. Freshwater Biology 2:77-82.
[CPUE, ABUNDANCE ESTIMATE, SAMPLING, FRESHWATER, GILL NET, VARIABILITY, METHODS]

Bannerot, S.P., and C.B. Austin. 1983. Using frequency distributions of catch per unit effort to measure fish-stock abundance. Transactions of the American Fisheries Society 112:608-617.
[CPUE, ABUNDANCE ESTIMATE,-SAMPLING, FISHERIES, CREEL SURVEY, FREQUENCY INDEX, METHODS ]

Berst, A.H., and A.M. McCombie. 1963. The spatial distribution of fish in gillnets. Journal of the Fisheries Research Board of Canada 20:735-742.
[CPUE, SAMPLING, DISTRIBUTION, GILL NET, SELECTIVITY, METHODS]

Beverton, R.J.H., and J.S. Holt. 1956. A review of methods for estimating mortality rates in fish populations, with special reference to sources of bias in catch sampling. Rapports et Proces-Verbaux des Reunions Conseil International pour 1'Exploration de la Mer 140:67-83.
(CPUE, MORTALITY ESTIMATE, SAMPLING, CONMERCIAL, FISHERIES, BIAS, METHODS, REVIEW, SYNTHESIS)

Bulkley, R.V. 1970. Fluctuations in abundance and distribution of common Clear Lake fishes as suggested by gillnet catch. Iowa State Journal of Science 44:413-422.
(CPUE, ABUNDANCE ESTIMATE, FRESHWATER, SAMPLING, GILL NET, METHODS, WALLEYES )

Carlander, K.D. 1944. Average gill net ratios, using standard experimental gill nets in Minnesota Lakes, 1941-1943. Minnesota Department of Conservation, Investigation Report No. 59: 4 pp.
(CPUE, ABUNDANCE ESTIMATE, SAMPLING, GILL NET, METHODS, WALLEYES)

Carle, F.L., and O.E. Maughan. 1980. Accurate and efficient estimation of benthic populations: comparison of removal estimation and conventional sampling techniques. Hydrobiologia 70:181-182.
[CPUE, ABUNDANCE ESTIMATE, REMOVAL, SAMPLING, BENTHOS, METHODS]

Carle, F.L., and M.R. Strubb. 1978. A new method for estimating population size from removal data. Biometrics 34:621-630.
{CPUE, ABUNDANCE ESTIMATE, REMOVAL, SAMPLING, METHODS}

Carothers, P.E., and M.E. Chittenden, Jr. 1985. Relationships between trawl catch and tow duration for penaeid shrimp. Transactions of the American Fisheries Society 114:851-856.
{CPUE, ABUNDANCE ESTIMATE, MARINE, SAMPLING, TRAWL, CATCHABILITY, METHODS}

Chapman, D.G., and D.S. Robson. 1960. The analysis of a catch curve. Biometrics 16:354-368.
[CPUE, ABUNDANCE ESTIMATE, AGE, MORTALITY ESTIMATE, METHODS}

Chapman, D.G., and G.I. Murphy 1965. Estimation of mortality and population from survey removal records. Biometrics 21:921-935.
[CPUE, ABUNDANCE ESTIMATE, MORTALITY ESTIMATE, REMOVAL, METHODS}

Collins, J.J. 1987. Increased catchability of the deep monofilament nylon gillnet and its expression in a simulated fishery. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):129-135.
[CPUE, ABUNDANCE ESTIMATE, COMMERCIAL, FISHERIES, GILL NET, CATCHABILITY, MODELS, METHODS}

Cox, D.R. 1972. Regression models and life tables (with discussion). Journal of the Royal Statistical Society, Series B34:187-220.
[CPUE, MORTALITY ESTIMATE, EMPIRICAL, MODELS, METHODS}

Craig, J.F., A. Sharma, and K. Smily. 1986. The variability of catches from multi-mesh gillnets fished in three Canadian lakes. Journal of Fish Biology 28:671-678.
{CPUE, ABUNDANCE ESTIMATE, SAMPLING, GILL NET, VARIABILITY, METHODS}

Cross, D.G., and B. Scott. 1975. The effect of electric fishing on the subsequent capture of fish. Journal of Fish Biology 7:349-357.
[CPUE, ABUNDANCE ESTIMATE, SAMPLING, ELECTROFISHER, METHODS1

DeLury, D.B. 1947. On the estimation of biological populations. Biometrics 3:145-167.
[CPUE, ABUNDANCE ESTIMATE, REMOVAL, METHODS}

Deriso, R.B., and A.M. Parma. 1987. On the odds of catching fish with angling gear. Transactions of the American Fisheries Society 116:244-256.
{CPUE, ABUNDANCE ESTIMATE, MARINE, COMMERCIAL, FISHERIES, SETLINE, METHODS}

Doubleday, W.G. 1976. A least squares approach to analyzing catch at age data. International Commission for the Northwest Atlantic Fisheries, Research Bulletin 12:69-81.
[CPUE, ABUNDANCE ESTIMATE, AGE, CATCH CURVE, METHODS]

Ehrhardt, N.M., and D.J. Die. 1988. Selectivity of gill nets used in the commercial Spanish mackerel fishery of Florida. Transactions of the American Fisheries Society 117:574-580.
[CPUE, FISHERY, COMMERCIAL, MARINE, SELECTIVITY, GILL NET]

Dupont, W.D. 1983. A stochastic catch-effort method for estimating animal abundance. Biometrics 39:1021-1033.
[CPUE, ABUNDANCE ESTIMATE, COMMERCIAL, FISHERIES, SETLINE, STOCHASTIC, MODELS, METHODS]

Foerster, R.E., and W.E. Ricker. 1938. The effectiveness of predator control in decreasing the mortality of young sockeye salmon (*Oncorhynchus nerka* Walbaum). Verh. Int. Verein. Limno. 8:151-167.
[CPUE, ABUNDANCE ESTIMATE, METHODS]

Foerster, R.E., and W.E. Ricker. 1941. The effect of reduction of predaceous fish on survival of young sockeye salmon at Cultus Lake. Journal of Fisheries Research Board of Canada 5:315-336.
[CPUE, ABUNDANCE ESTIMATE, METHODS]

Fowler, C.W. 1980. A rationale for modifying effort by catch, using the sperm whale of the North Pacific as an example. International Whaling Commission Report of the Commission(special issue 2), SC/30/document 52:99-102.
[CPUE, SAMPLING, COMMERCIAL, WHALES, FISHERIES, CATCHABILITY, METHODS]

Garrod, D.J. 1964. Effective fishing effort and the catchability coefficient, q. Rapports et Proces-Verbaux des Reunions Conseil International pour l'Exploration de la Mer 155:66-70.
[CPUE, ABUNDANCE ESTIMATE, COMMERCIAL, FISHERIES, CATCHABILITY, METHODS]

Gavaris, S. 1980. Use of a multiplicative model to estimate catch rates and effort from commercial data. Canadian Journal of Fisheries and Aquatic Sciences 34:2272-2275.
[CPUE, ABUNDANCE ESTIMATE, COMMERCIAL, FISHERIES, GILL NET, CATCHABILITY, MODEL, METHODS]

Gulin, V.V., and G.P. Rudenko. 1973. Procedure for assessment of fish production in lakes. Journal of Ichthyology 13:813-823.
[STOCK ASSESSMENT, PRODUCTION, FRESHWATER, METHODS]

Gulland, J.A. 1964a. *Catch* per unit effort as a measure of abundance. Rapports et Proces-Verbaux des Reunions Conseil International pour l'Exploration de la Mer 155:8-14.
[CPUE, ABUNDANCE ESTIMATE, COMMERCIAL, MARINE, FISHERIES, METHODS]

Gulland, J.A. 1964b. The reliability of catch per unit effort data as a measure of abundance in North Sea trawl fisheries. Rapports et Proces-Verbaux des Reunions Conseil International pour l'Exploration de la Mer 155:99-102.
[CPUE, ABUNDANCE ESTIMATE, COMMERCIAL, MARINE, FISHERIES, METHODS]

Gulland, J.A. 1978. Assessment of a fishery. Pages 274-288 in T. Bagenal, editor. Methods for assessment of fish production in fresh waters. Blackwell Scientific Publications, Oxford, England.
[CPUE, ABUNDANCE ESTIMATE, COMMERCIAL, MARINE, FISHERIES, METHODS]

Hamley, J.M. 1975. Review of gillnet selectivity. Journal of the Fisheries Research Board of Canada 32:1943-1969.
[CPUE, ABUNDANCE ESTIMATE, SAMPLING, SELECTIVITY, GILL NET, METHODS]

Bamley, J.M. 1980. Sampling with gill nets. Pages 37-53 *in T.* Backiel and R. Welcome, editors. Guidelines for sampling fish in fresh water. European Inland Fisheries Advisory Committee Technical Paper 33, Food and Agricultural Organization of the United Nations, Rome, Italy.
[CPUE, ABUNDANCE ESTIMATE, SAMPLING, FRESHWATER, GILL NET, METHODS]

Hamley, J.M., and H.A. Regier. 1973. Direct estimates of gill net selectivity to walleye (*Stizostedion vitreum vitreum*). Journal of the Fisheries Research Board of Canada 30:817-830.
[CPUE, ABUNDANCE ESTIMATE, SAEPLING, SELECTIVITY, GILL NET, METHODS, WALLEYES]

Hoenig, J.M., D.M. Heisey, W.D. Lawing, and D.H. Schupp. 1987. An indirect rapid methods approach to assessment. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):324-338.
[STOCK ASSESSMENT, CPUE, STANDING CROP, BIOMASS, YIELD]

Houser, A., and A.E. Bryant. 1967. Sampling reservoir fish populations using midwater trawls. Pages 391-404 *in* F.F. Fish et al., editors. Reservoir fisheries resources symposium. American Fisheries Society, Bethesda, Maryland, USA.
[CPUE, ABUNDANCE ESTIMATE, SAMPLING, FRESHWATER, TRAWLS, METHODS]

Isbell, G.L., and M.R. Rawson. 1989. Relations of gill-net catches of walleyes and angler catch rates in Ohio waters of western Lake Erie. North American Journal of Fisheries Management 9:41-46.
[CPUE, AGE COMPOSITION, FRESHWATER, GILL NET, METHODS, ANGLING, WALLEYES]

Jacobson, L.D., W.R. MacCallum, and G.R. Spangler. 1987. Biomass dyamics of Lake Superior lake herring (*Coregonus artedii*): application oF Schnute'e difference model. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):275-288.
[CPUE, ABUNDANCE ESTIMATE, SAMPLING, COMMERCIAL, FISHERIES, GREAT LAKES, CATCHABILITY, GILL NET, METHODS]

Jester, D.B. 1973. Variations in catchability of fishes with color of gillnets. Transactions of the American Fisberies Society 102:109-115.
{CPUE, SAMPLING, CATCHABILITY, COLOR, GILL NET, METHODS}

Jester, D.B. 1977. Effects of color, mesh size, and fishing in seasonal concentrations, and baiting on catch rates of gillnets. Transactions of the American Fisheries Society 106:43-56.
[CPUE, SAMPLING, CATCHABILITY, COLOR, MESH SIZE, GILL NET, METHODS}

Kennedy, W.A. 1950. The determination of optimum size of mesh for gill nets in Lake Manitoba. Transactions of the American Fisheries Society 79:167-179.
{CPUE, COMMERCIAL, FISHERIES, SELECTIVITY, MESH SIZE, GILL NET, METHODS}

Kennedy, W.A. 1951. The relationship between fishing effort by gillnets to the interval between lifts. Journal of the Fisheries Research Board of Canada 8:264-274.
{CPUE, ABUNDANCE ESTIMATE, SAMPLING, CATCHABILITY, GILL NET, METHODS}

Kimura, D.K. 1981. Standardized measures of relative abundance based on modelling log(c.p.u.e.), and their application to Pacific ocean perch (*Sebastes alutus*). Journal du Conseil, Conseil International pour l'Exploration de la Mer 39:211-218.
[CPUE, RELATIVE ABUNDANCE, COMMERCIAL, MARINE, FISHERIES, MODELS, METHODS)

Kimura, D.K. 1988. Analyzing relative abundance indices with log-linear models. North American Journal of Fisheries Management 8:175-180.
{CPUE, RELATIVE ABUNDANCE, COMMERCIAL, FISHERIES, SETLINE, MODELS, METHODS}

King, T.A., J.C. Williams, W.D. Davies, and W.L. Shelton. 1981. Fixed versus random sampling of fishes in a large reservoir. Transaction of the American Fisheries Society. 110:563-568.
{RELATIVE ABUNDANCE, RANDOM SAMPLING, FIXED SAMPLING, METHODS}

Kioke, A., and S. Takeuchi. 1982. Saturation of gillnet for pondsmelt, *Hypomesus transpacificus nippoaensis.* Bulletin of the Jappanese Society for Scientific Fisheries 48:1711-1716.
{CPUE, SAHPLING, FRESHWATER, FISHERIES, CATCHABILITY, SATURATION, GILL NET, METHODS}

Kushneriuk, R.S. 1982. Sampling problems in estimating freshwater fish abundance. Master's thesis. University of Toronto, Toronto.
{CPUE, ABUNDANCE ESTIMATE, SAMPLING, METHODS}

Layher, W.G., and O.E. Maughan. 1984. Comparison efficiencies of three sampling techniques for estimating fish populations in small streams. Progressive Fish-Culturist 46:180-184.
{CPUE, ABUNDANCE ESTIMATE, FRESHWATER, SAMPLING, METHODS}

Leslie, P.H., and D.H.S. Davis. 1939. An attempt to determine the absolute number of rats on a given area. Journal of Animal Ecology 8:94-113.
{CPUE, ABUNDANCE ESTIMATE, SAMPLING, METHODS}

Lewis, C.A., D.H. Schupp, W.W. Taylor, J.J. Collins, and R.W. Hatch. 1987. Predicting Great Lakes fish yields: tools and constraints. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):411-416.
{STOCK ASSESSMENT, YIELD PREDICTION, GREAT LAKES, METHODS, SYNTHESIS]

MacCall, A.D. 1976. Density-dependence of catchability coefficient in the California Pacific sardine, *Sardinops sagax caerula,* purse seine fishery. Marine Resources Commision California Cooperative Oceanic Fisheries Investigation Report 18:136-148.
{CPUE, ABUNDANCE ESTIMATE, COMMERCIAL, FISHERIES, CATCHABILITY, PURSE SEINE, METHODS}

MacGuinness, K.A. 1984. Equations and explanations in the study of species-area curves. Biological Reviews of the Cambridge Philosophical Society 59:423-440.
{CPUE, ABUNDANCE ESTIMATE, SAMPLING, THEORY}

Meth, F. 1970. Saturation in gillnets. Master's thesis. University of Toronto, Toronto.
{CPUE, ABUNDANCE ESTIMATE, SAMPLING, CATCHABILITY, SATURATION, GILL NET, METHODS}

McCrombie, A.M. 1961. Gill-net selectivity of lake whitefish from Goderich-Bayfield Area, Lake Huron. Transactions of the American Fisheries Society 90:337-340.
[CPUE, COMMERCIAL, GREAT LAKES, FISHERIES, SELECTIVITY, GILL NET)

McCrombie, A.M., and F.E.J. Fry. 1960. Selectivity of gill nets for lake whitefish, *Coregonus clupeaformis.* Transactions of the American Fisheries Society 89:176-184.
[CPUE, COMMERCIAL, GREAT LAKES, FISHERIES, SELECTIVITY, GILL NET, METHODS}

Minns, C.K., and D.A. Hurley. 1988. Effect of net length and set time on fish catches in gill nets. North American Journal of Fisheries Management 8:216-223.
{CPUE, SAMPLING, TIER, EFFORT, GILL NET, METHODS}

Moyle, J.B. 1949. Some indices of lake productivity. Transactions of the American Fisheries Society 79?:195-204.
{CPUE, INDEX, SAMPLING, FRESHWATER, GILL NET, METHODS}

Moyle, J.B. 1950. Gill nets for sampling fish populations in Minnesota waters. Transactions of the American Fisheries Society 79?:195-204.
{CPUE, SAMPLING, FRESHWATER, GILL NET, METHODS}

Moyle, J.B., J.H. Kuehn, and C.R. Burrows. 1950. Fish populations and catch data from Minnesota lakes. Transactions of the American Fisheries Society 78?:163-175.
{CPUE, POPULATION INDEX, SAMPLING, FRESHWATER, GILL NET, METHODS}

Moyle, J.B., and R. Lound 1960. Confidence limits associated with means and medians of series of net catches. Transactions of the American Fisheries Society 89:53-58.
[CPUE, INDEX, SAMPLING, FRESHWATER, GILL NET, STATISTICS, METHODS}

Neyman, J. 1949. On the problem of estimating the number of schools of fish. University of California Publications in Statistics 1:21-36.
{CPUE, ABUNDANCE ESTIMATE, THEORY, METHODS}

Nielsen, L.A. 1983. Variation in the catchability of yellow perch in an otter trawl. Transactions of the American Fisheries Society 112:53-59.
{CPUE, ABUNDANCE ESTIMATE, SAMPLING, FRESHWATER, CATCHABILITY, TRAWL, METHODS I

Novotny, D.W., and G.R. Priegel. 1974. Electrofishing boats -- improved designs and operational guidelines to increase the effectiveness of boom shockers. Wisconsin Department of Natural Resources Technical Bulletin 73.
{CPUE, ABUNDANCE ESTIMATE, SAMPLING, ELECTROFISHERY METHODS}

Paloheimo, J.E. 1961. Studies on estimation of mortalities: I. Comparison of a method described by Beverton and Holt and a new linear formula. Journal of the Fisheries Research Board of Canada 18:645-662.
{CPUE, MORTALITY ESTIMATES, MODELS, METHODS}

Paloheimo, J.E. 1980. Estimation of mortality rate in fish populations. Transactions of the American Fisheries Society 109:378-387.
{CPUE, MORTALITY ESTIMATES, METHODS}

Paloheimo, J.E., and L.M. Dickie. 1964. Abundance and fishing success. Rapports et Proces-Verbaux des Reunions Conseil International pour l'Exploration de la Mer 155:152-163.
[CPUE, ABUNDANCE ESTIMATE, SAMPLING, COMMERCIAL, FISHERIES, GILL NET, METHODS }

Parkinson, E.A., J. Berkowitz, and C.J. Bull. 1988. Sample size requirements for detecting changes in some fisheries statistics from small trout lakes. North American Journal of Fisheries Management 8:181-190.
{CPUE, SAMPLE SIZE, SAMPLING, COMMERCIAL, FISHERIES, GILL NET, METHODS}

Pella, J.J. 1969. A stochastic model for purse seining in a two-species fisheries. Journal of Theoretical Biology 22:209-226.
[CPUE, SAMPLING, COMMERCIAL, FISHERIES, PURSE SEINE, MULTISPECIES, MODELS, METHODS}

Pierce, R.B., D.W. Coble, and S.D. Corley. 1985. Influence of river stage on shoreline electrofishing catches in the upper Mississippi River. Transactions of the American Fisheries Sosiety 114:857-860.
(CPUE, SAMPLING, ENVIRONMENTAL, ELECTROFISHING, METHODS)

Polovina, J. 1986. A variable catchability version of the Leslie model with application to an intensive fishing experiment on a multispecies stock. U.S. National Marine Fisheries Service Fishery Bulletin 84:423-428.
(CPUE, SAMPLING, EXPLOITATION, FISHERIES, MULTISPECIES, MODELS, METHODS

Pope, J.G. 1980. Some consequences for fisheries management of aspects of the behavior of pelagic fish. Rapports et Proces-Verbaux des Reunions Conseil International pour 1'Exploration de la Mer 177:466-476.
(CPUE, ABUNDANCE ESTIMATE, SAMPLING, COMMERCIAL, FISHERIES, BEHAVIOR, METHODS

Pope, J.G., and D.J. Garrod. 1975. Sources of error in catch and effort quota regulations with particular reference to,variations in the catchability coefficients. ICNAF Resource Bulletin 11:17-30.
(CPUE, SAMPLING ERROR, REGULATIONS, FISHERIES, CAPABILITY, METHODS

Powles, H. 1981. What does purse-seine catch per unit effort measure? A simple fishery model. CAFSAC Research Document 81/36.
(CPUE, ABUNDANCE ESTIMATE, SAMPLING, COMMERCIAL, FISHERIES, PURSE SEINE, METHODS

Raleigh, R.F., and C. Short. 1981. Depletion sampling in stream ecosystems: assumptions and techniques. Progressive Fish-Culturist 43:115-120.
(CPUE, ABUNDANCE ESTIMATE, DEPLETION SAMPLING, FRESHWATER, METHODS}

Radovich, J. 1976. Catch-per-unit-effort: fact, fiction or dogma. Marine Resources Commision California Cooperative Oceanic Fisheries Investigation Report 18:31-33.
(CPUE, ABUNDANCE ESTIMATE, SAMPLING, METHODS)

Regier, H.A., and D.S. Robson. 1966. Selectivity of gill nets, especially to lake whitefish. Journal of the Fisheries Research Board of Canada 23:423-454.
(CPUE, COMMERCIAL, FISHERIES, FRESHWATER, GILL NET, SELECTIVITY, METHODS}

Richards, L.J., and J.T. Schnute. 1986. An experimental and statistical approach to the question: is CPUE an index of abundance? Canadian Journal of Fisheries and Aquatic Sciences 43:1214-1227.
(CPUE, ABUNDANCE ESTIMATE, SAMPLING, STATISTICS, METHODS}

Ricker, W.E. 1940. Relation of catch per unit effort to abundance and rate of exploitation. Journal of the Fisheries Research Board of Canada 5:43-70.
(CPUE, ABUNDANCE ESTIMATE, EXPLOITATION, COMMERCIAL, FISHERIES, METHODS)

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191:1-382.
(STOCK ASSESSMENT, ABUNDANCE ESTIMATE, METHODS, SYNTHESIS}

Robson, D.S., and D.G. Chapman. 1961. Catch curves and mortality rates. Transactions of the American Fisheries Society 90:181-189.
(STOCK ASSESSMENT, CATCH CURVE. AGE, MORTALITY ESTIMATES, METHODS}

Robson, D.S., and H.A. Regier. 1971. Estimation of population number and mortality rates. IBP (International Biological Programme) Handbook 3:131-165.
{STOCK ASSESSMENT, ABUNDANCE ESTIMATE, MORTALITY ESTIMATES, METHODS, SYNTHESIS}

Robson, D.S., and G.R. Spangler. 1978. Estimation of population abundance and survival. Pages 26-51 *in* S.D. Gerking, editor. Ecology of freshwater fish production. John Wiley and Sons, New York, New York. USA.
[STOCK ASSESSMENT, ABUNDANCE ESTIMATE, MORTALITY ESTIMATES, METHODS, SYNTHESIS)

Saila, S.B., and K. Erzini. 1987. Empirical approach to multispecies stock assessment. Transactions of the American Fisheries Society 116: 601-611.
{CPUE, STOCK ASSESSMENT, MULTISPECIES, MODELS, METHODS}

Schnute, J. 1985. A general theory for analysis of catch and effort data. Canadian Journal of Fisheries and Aquatic Sciences 42:414-429.
{CPUE, SAMPLING, METHODS, THEORY}

Seber, G.A.F. 1973. The estimation of animal abundance. Griffin, London. 506 pp.
{STOCK ASSESSMENT, ABUNDANCE ESTIMATE, METHODS, SYNTHESIS}

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters. Griffin, New York.
(STOCK ASSESSMENT, ABUNDANCE ESTIMATE, METHODS, SYNTHESIS}

Seber, G.A.F. 1986. A review of estimating animal abundance. Biometrics 42:267-292.
{STOCK ASSESSMENT, ABUNDANCE ESTIMATE, METHODS, REVIEW}

Sechin, Yu. T. 1969. A mathematical model for the selectivity curve of a gillnet. Rybnoe Khoziaistvo 45(9):56-58. Translated from Russian: International Pacific Halibut Commission, Seattle, Washington.
(MODEL, SELECTIVITY, GILL NET)

Serns, S.L. 1982. Relationship of walleye fingerling density and electrofishing catch per effort in northern Wisconsin lakes. North American Journal of Fisheries Management 2:38-44.
{CPUE, ABUNDANCE ESTIMATE, SAMPLING, ELECTROFISHING, METHODS, WALLEYES)

Searns, S.L. 1983. Relationship between electrofishing catch per unit effort and density of walleye yearlings. North American Journal of Fisheries Management 3:451-452.
{CPUE, ABUNDANCE ESTIMATE, SAMPLING, ELECTROFISHING, METHODS, WALLEYES)

Skalski, J.R., D.S. Robson, and C.L. Matsuzaki. 1983. Competing probabilistic models for catch-effort relationships in wildlife censuses. Ecological modelling 19:299-307.
{CPUE, ABUNDANCE ESTIMATE, SAMPLING, WILDLIFE, METHODS]

Spangler, G.R., K.H. Loftus, and W.Y. Christie. 1987. Introduction to the international symopsium on stock assessment and yield prediction (ASPY). Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):7-9.
{STOCK ASSESSMENT, ABUNDANCE ESTIMATE, YIELD PREDICTION, SYNTHESIS}

Steer, G.J., N.B.F. Cousens, ii. Stiff, and K.D. Hyatt. 1986. An analysis of gear selectivity and sources of bias in estimates of ages and stock composition of the 1980-1984 Barkley Sound sockeye salmon (*Oncorhynchus nerka*) catch. Canadian Technical Report of Fisheries and Aquatic Sciences, Number 1445.
{CPUE, STOCK ASSESSMENT, AGE, SAMPLING BIAS, COMMERCIAL, FISHERIES. GILL NET, SELECTIVITY, METHODS}

Uchida, R.N. 1967. Catch and estimates of fishing effort and apparent abundance in the fishery for skipjack tuna (*Katsuwonus pelamis*) in Hawaiian waters, 1952-62. United States Fish and Wildlife Service Fisheries Bulletin: Volume 66, No. 2.
[CPUE, STOCK ASSESSMENT, COMMERCIAL, FISHERIES, METHODS]

Ulltang, 0. 1976. Catch per unit of effort in the Norwegian purse seine fishery for Atlanto-Scandian (Norwegian spring spawning) herring. FAO Fisheries Technical Paper 155:91-101.
[CPUE, STOCK ASSESSNENT, COMMERCIAL, FISHERIES, PURSE SEINE, MARINE}

Ulltang, 0. 1976. Factors affecting the reaction of pelagic fish stocks to exploitation and requiring a new approach to assessment and management. Rapports et Proces-Verbaux des Reunions Conseil International pour l'Exploration de la Mer 177:489-504.
[CPUE, EXPLOITATION, COMPENSATION, COMMERCIAL, FISHERIES, METHODS]

Welcomme, R.L. 1975. Symposium on the methodology for the survey, monitoring and appraisal of fishery resources in lakes and large rivers. EIFAC (European Inland Fisheries Advisory Commission) Technical Paper 23, Supplement 1.
{CPUE, STOCK ASSESSMENT, SAMPLING, COMMERCIAL, FISHERIES, FRESHWATER, METHODS}

Willis, D.W. 1987. Use of gill net data to provide a recruitment index for walleyes. North American Journal of Fisheries Management 7:591-592.
(CPUE, RECRUITMENT INDEX, SAMPLING, GILL NET, METHODS, WALLEYES}

Willis, D.W., K.D. McCloskey, and D.W. Gabelhouse, Jr. 1985. Calculation of stock density indices based on adjustment for efficiency of gill-net mesh size. North American Journal of Fisheries Management 5:126-127.
{CPUE, STOCK ASSESSMENT. SAMPLING, GILL NET, MESH SIZE, METHODS}

Winters, G.H., and J.P. Wheeler. 1985. Interaction between stock area, stock abundance, and catchability coefficient. Canadian Journal of Fisheries and Aquatic Sciences 42:989-998.
{CPUE, STOCK **ABUNDANCE,** AREA, **COMMERCIAL,** FISHERIES, **CATCHABILITY,** GILL NET, METHODS, MODELS, MARINE}

B. Creel Survey and Census

Carlander, K.D., and S. Eddy. 1940. Selectivity of sampling methods in relation to fish growth studies. Minnesoota Department of Conservation, Investigation Report No. 11: 11 pp.
**{CREEL,** GROWTB, SELECTIVITY, **WALLEYES}**

Carline, R.F. 1972. Biased harvest estimates from a postal survey of a sport fishery. Transactions of the American Fisheries Society 101:262-266.
{CREEL, SURVEY, BIAS, **FRESHWATER}**

DiCostanzo, C.J. 1956. Clear Lake creel census and evaluation of sampling techniques. Pages 17-29 *in* K.D. Carlander, editor. Symposium on sampling problems in creel census. Iowa State College, Ames, Iowa.
{CREEL, SAMPLING, **METHODS,** FRESHWATER, WALLEYES}

Jenkins, R.M., and D.I. Morais. 1971. Reservoir sport fishing effort and harvest in relation to environmental variables. American Fisheries Society Special Publication 8:371-384.
{CREEL, CPUE ENVIRONMENTAL, FRESHWATER1

Jennings, T. 1968. Summary of 22 consecutive years of creel census on Spirit Lake. Proceedings of the Iowa Academy of Sciences 75:159-163.
(CREEL, **TIME** SERIES, FRESHWATER, WALLEYES)

Jennings, T. 1969. Summary of 23 consecutive years of creel census on West Okoboji. Proceedings of the Iowa Academy of Sciences 76:206-210.
(CREEL, **TIME** SERIES, FRESHWATER, WALLEYES)

Moyle, J.B., and D.R. Franklin. 1957. Quantitative creel census on 12 Minnesota lakes. Transactions of the American Fisheries Society 85:28-38.
**{CREEL,** FRESHWATER, **METHODS}**

Nelson, K.K. 1980. A qualitative and quantitative roving creel census with a modification of the Weitman-Anderson methodology. Minnesota Department of Natural Resources Fish Management Report No. 25: 37 pp.
(**CREEL, FRESHWATER, METHODS}**

Peterman, R.M., and G.J. Steer. 1981. Relations between sport-fishing catchability coefficients and salmon abundance. Transactions of the American Fisheries Society 110:585-593.
{CREEL, **ABUNDANCE,** CATCHABILITY, FRESHWATER, SALMONIDS]

Shuter, B.J., J.E. Matuszek, and H.A. Regier. 1987. Optimal use of creel survey data in assessing population behavior: Lake Opeongo lake trout (Salvelinus *namaycush)* and smallmouth bass Micropterus *dolomieui)* , 1936-83. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):229-238.
(CREEL, **TIME** SERIES, BEHAVIOR, FRESHWATER, SALMONIDS, SMALLMOUTH BASS)

C. lark-recapture

Arnason, **A.N.**, and R.H. Mills. 1986. The detection of handling mortality and its effects on Jolly-Seber estimates for mark-recapture experiments. Canadian Journal of Fisheries and Aquatic Sciences 44 (Supplement 1):64-73.
(MARK-RECAPTURE, STATISTICS, **HANDLING** MORTALITY, METHODS)

Brownie, C., D.R. Anderson, K.P. Burnham, and D.S. Robson. 1985. Statistical inference from band recovery data -- a handbook, 2nd edition. U.S. Fish and Wildlife Service Resource Publication 156.
(MARK-RECAPTURE, WILDLIFE, REVIEW, **METHODS**}

Brownie, C., and K.H. Pollock. 1985. Analysis of multiple capture-recapture data using band-recovery methods. Biometrics 41:411-420.
(MARK-RECAPTURE, **STATISTICS, METHODS**}

Burnham, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph Number 5, Bethesda, Maryland.
{**MARK-RECAPTURE, SURVIVAL, METHODS,** COLUMBIA RIVER}

Cooper, G.P. 1952. Estimation of fish populations in Michigan lakes. Transactions of the American Fisheries Society 81:4-16.
{**MARK-RECAPTURE,** ABUNDANCE **ESTIMATES,** FRESHWATER}

Cormack, R.M. 1969. The statistics of capture-recapture methods. Oceanography and Marine Biology 6:455-506.
{**MARK-RECAPTURE,** STATISTICS, METHODS)

Cormack, R.M. 1972. The logic of capture-recapture estimates. Biometrics 28:337-343.
(MARK-RECAPTURE, **ABUNDANCE ESTIMATES,** STATISTICS, **METHODS**}

Cormack, R.M. 1973. Common sense estimates from capture-recapture studies. Pages 225-234 *in* M.S. Bartlet and R.W. Hiorns, editors. The mathematical theory of the dynamics of biological populations. Academic Press, London.
{MARK-RECAPTURE, ABUNDANCE **ESTIMATES,STATISTICS**}

Cormack, R.M. 1979. Models for capture-recapture. Pages 217-255 *in* R.M. Cormack, G.P. Patil, and D.S. Robson, editors. Statistical ecology,

volume 5. Sampling biological populations. International Co-operative Publishing House, Fairland, Maryland.
[MARK-RECAPTURE, ABUNDANCE ESTIMATES, MODELS]

Crowe, W.R. 1955. Numerical abundance and use of a spawning run of walleyes in the Muskegon River, Michigan. Transactions of the American Fisheries Society 84:125-136.
[MARK-RECAPTURE, ABUNDANCE ESTIMATES, FRESHWATER, SPAWNERS, WALLEYES]

Crosbie, S.F., and B.F.J. Manley. 1985. A new approach for parsiminous modeling of capture-mark-recapture studies. Biometrics 41:385-398.
[MARK-RECAPTURE, MODELS]

Crowe, W.R., E. Karvelis, and L.S. Joeris. 1963. The movements, heterogeneity, and rate of exploitation of walleyes in northern Green Bay, Lake Michigan, as determined by tagging. International Commission Northwestern Atlantic Fish Commission, Special Publication 4:38-41.
[MARK-RECAPTURE, MOVEMENTS, DISTRIBUTION, EXPLOITATION, FRESHWATER, WALLEYES]

Emery, L., and R. Wydoski. 1987. Marking and tagging of aquatic animals: an indexed bibliography. U.S. Fish and Wildlife Service, Resource Publication Number 165:1-57.
[MARK-RECAPTURE, BIBLIOGRAPHY]

Hammersley, J.M., and R.J. Gilbert. 1984. Capture-recapture analysis. Biometrics 40:265-278.
[MARK-RECAPTURE, STATISTICS]

Hightower, J., and R.J. Gilbert. 1984. Using the Jolly-Seber model to estimate population size, mortality, and recruitment for a reservoir fish population. Transactions of the American Fisheries Society 113:633-641.
[MARK-RECAPTURE, ABUNDANCE ESTIMATES, MORTALITY, RECRUITMENT, MODELS, FRESHWATER]

Jones, R. 1963. A review of methods of estimating population size from marking experiments. Rapports et Proces-Verbaux des Reunions Conseil International pour l'Exploration de la Mer 155:202-209.
[MARK-RECAPTURE, ABUNDANCE ESTIMATES, METHODS, REVIEW]

Jones, R. 1976. The use of marking data in fish population analysis. Food and Agricultural Organization, United Nations, Fisheries Technical Paper No. 153. Rome, Italy. 42 pp.
[MARK-RECAPTURE, STOCK ASSESSMENT]

McCann, J.A., and K.D. Carlander. 1970. Mark and recovery estimates of fish populations in Clear Lake, Iowa, 1958-1959. Iowa State Journal of Science 44:369-403.
[MARK-RECAPTURE, ABUNDANCE ESTIMATES, FRESHWATER]

Otis, D.L., K.P. Burnham, G.C. White, and D.R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monograph 62.
[MARK-RECAPTURE, STATISTICS, CLOSED POPULATIONS, REVIEW]

Pollock, K.H. 1981. Capture-recapture models: a review of current methods, assumptions, and experimental design. Studies in Avian Biology 6:426-435.
[MARK-RECAPTURE, ASSUMPTIONS, MODELS, REVIEW]

Pollock, K.H., and R.H.K. Mann. 1983. Use of an age-dependent mark-recapture model in fisheries research. Canadian Journal of Fisheries and Aquatic Sciences 40:1449-1455.
[MARK-RECAPTURE, AGE-STRUCTURE,MODEL]

Robson, D.S. 1969. Mark-recapture methods of population estimation. Pages 120-140 *in* N.L. Johnson and H. Smith, Jr., editors. New developments in survey sampling. Wiley Interscience, New York.
[MARK-RECAPTURE, ABUNDANCE ESTIMATES, METHODS}

Robson, D.S., and H.A. Regier. 1964. Sample size in Peterson mark-recapture experiments. Transactions of the American Fisheries Society 93:181-189.
{MARK-RECAPTURE, ABUNDANCE ESTIMATES, SAMPLE SIZE}

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters, 2nd edition. Macmillan, New York.
[MARK-RECAPTURE, ABUNDANCE ESTIMATES, STATISTICS]

Seber, G.A.F. 1986. A review of estimating animal abundance. Biometrics 42:267-292.
[MARK-RECAPTURE, ABUNDANCE ESTIMATES, STATISTICS, REVIEW]

Skalsli, J.R. 1985. Construction of cost functions for tag-recapture research. Wildlife Society Bulletin 13:273-283.
(MARK-RECAPTURE, STATISTICS, ECONOMICS)

White, G.C., D.R. Anderson, K.P. Burnham, and D.L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory, LA-8787-NERP, Los Alamos, New Mexico.
[MARK-RECAPTURE REMOVAL,SAMPLING, CLOSED POPULATION,STATISTICS REVIEW]

Youngs, W.D., and D.S. Robson. 1975. Estimating survival rate from tag returns: model tests and sample size determination. Journal of the Fisheries Research Board of Canada 32:2365-2371.
[MARK-RECAPTURE, STATISTICS, MORTALITY. MODEL, SAMPLE SIZE]

D. Hydroacoustics - total ichthyomass

Bazigos, G. 1973. The sampling design of the catch assessment survey (CAS). FAO Working Paper. FI: DP/URT/71/012/1.

Burczunski, J., and R. Johnson. 1986. Application *of* dual-beam survey techniques to limnetic populations of juvenile sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 43:1776-1778.
{HYDROACOUSTICS, DUAL-BEAM, POPULATION, FRESHWATER, SALMON}

Burczynski, J.J., P.H. Michalets, and G.M. Marrone. 1987. Hydroacoustic assessment of the abundance and distribution of rainbow smelt in Lake Oahe. North American Journal of Fisheries Management 7:106-116.
{HYDROACOUSTICS, ABUNDANCE ESTIMATE, DISTRIBUTION, FRESHWATER}

Chapman, D.W. 1974. Acoustical estimates of biomass of pelagic fish in Lake Tanganyika. Paper presented to the European Inland Fishing Advisory Commission, Symposium on methodology for survey, monitoring and appraisal of fishery resources in lakes and large rivers. Aviemore, Scotland, 2-4 May 1974. EIFAC Symp. Pap., 66:23 p.
{HYDROACOUSTICS, ABUNDANCE ESTIMATE, BIOMASS, FRESHWATER, AFRICA]

Coulter, G.W. 1970. Population changes within a group of fish species in Lake Tanganyika following their exploitation. Journal of Fish Biology 2:329-353.
{HYDROACOUSTICS, POPULATION DYNAMICS, SYNECOLOGY, FRESHWATER, AFRICA}

Dragesund, O., and S. Olsem. 1965. On the possibility of estimation year class strength by measuring echo abundance of O-group fish. Fisk. Dir. Skr. Ser. Havunders 13(8):47-75.
{HYDROACOUSTICS, ABUNDANCE ESTIMATE, YEAR CLASS}

Ehrenberg, J.E. 1984. Dual-beam target strength system. Acoustic systems for the assessment of fisheries. R.B. Mitson, editor. FAO (Food and Agriculture Organization of the United Nations) Fisheries Circular 778:71-80.
{HYDROACOUSTICS, DUAL-BEAR, METHODS]

Gyldenge, G.G., B.H. Ransom, W.R. Ross. 1983. Hydroacoustic assessment of downstream migrating salmon and steelhead at Rock Island Dam in 1982. Final report to Chelan County PUD No. 1. BioSonics, Inc., Seattle, Washington.
{HYDROACOUSTICS, COLUMBIA RIVER, SALMONIDS}

Johnson, L., A. Murphy, C. Rawlinson. 1985. Hydroacoustic assessment of downstream migrating salmonids at Lower Monumental Dam in spring 1985. (Contract DE-A C79-85 BP23174) to Bonneville Power Administration, Portland, Oregon.
{HYDROACOUSTICS, COLUMBIA RIVER, SALMONIDS}

Johnston, J.M. 1981. Development and evaluation of hydroacoustic techniques for instantaneous fish population estimates in shallow lakes. Washington State Game Department, Olympia, Washington. 59 p.
{HYDROACOUSTICS, ABUNDANCE ESTIMATE, METHODS, FRESHWATER}

Lenarz, W.H., and J.H. Green. 1971. Electronic processing of acoustical data for fishery research. Journal of Fisheries Research Board of Canada 28:446-447.
{HYDROACOUSTICS, METHODS}

Moose, P.H. and J.E. Ehrenberg. 1971. An expression of the variance of abundance estimates using a fish echo integrator. Journal of Fisheries Research Board of Canada. 28:1293-1301.
{HYDROACOUSTICS, ABUNDANCE ESTIMATE, STATISTICS]

Mulligan, T.J., R. Kieser, and T. Gjerns. 1987. A model for comparing fish density estimates from seine catches and from echo integration. Canadian Journal of Fisheries and Aquatic Sciences 44:1024-1030.
{HYDROACOUSTICS, PURSE SEINE, ABSOLUTE ABUNDANCE, RELATIVE ABUNDANCE, CALIBRATION, METHODS, MARINE}

Raemhild, G.A. 1985?. The application of hydoracoustic techniques in solving fishery problems related to hydroelectric dams. BioSonics, Inc., Seattle, Washington.
{HYDROACOUSTICS, METHODS, COLUMBIA RIVER, SALMONIDS}

Raemhild, G.A., G.E. Johnson, and C.M. Sullivan. 1984. Hydroacoustic monitoring of downstream migrant salmon and steelhead at Wells Dam in Spring 1984. (Contract A179-84BP-13099) to Bonneville Power Administration, Portland, Oregon.
{HYDROACOUSTICS, COLUMBIA RIVER, SALMONIDS}

Raemhild, G.A., R. Nason, and S. Hays. 1985. Hydroacoustic studies of downstream migrating salmonids at hydropower dams: two case studies. Paper presented at the American Fisheries Society Symposium on Small Hydropower and Fisheries, Denver, Colorado, May 1-3, 1985. 244-250.
{HYDROACOUSTICS, COLUMBIA RIVER, SALMONIDS}

Raemhild, G.A., B.H. Ransom, W.R. Ross, and M. Dimmitt. 1984. Hydroacoustic assessment of downstream migration salmon and steelhead at Rock Island Dam in 1983. Report to Chelan County PUD No.1. BioSonics, Inc., Seattle, Washington.
{HYDROACOUSTICS, COLUMBIA RIVER, SALMONIDS}

Raemhild, G.A., T.W. Steig, R.H. Riley. 1983. Hydroacoustic assessment of downstream migrating salmon and steelhead at Rocky Reach Dam in 1982. Final report to Chelan County PUD No.1. BioSonics, Inc., Seattle, Washington.
{HYDROACOUSTICS, COLUMBIA RIVER, SALMONIDS}

Raemhild, G.A., T.W. Steig, R.H. Riley, and S.V. Johnston. 1984. Hydroacoustic assessment of downstream migration salmon and steelhead at Rocky Reach Dam in 1983. Report to Chelan County PUD. No. 1, BioSonics, Inc., Seattle, Washington.
{HYDROACOUSTICS, COLUMBIA RIVER, SALMONIDS]

Steig, T.W. and W.R. Johnson. 1986. Hydroacoustic assessment of downstream migration salmonids at The Dalles Dam in spring and summer 1985. (Contract DE-AC79-85 BP23174) to Bonneville Power Administration, Portland Oregon.
{HYDROACOUSTICS, COLUMBIA RIVER, SALMONIDS}

Thorne, R.E. 1979. Hydroacoustic estimates of adult sockeye salmon (*Oncorhynchus nerka*) in Lake Washington, 1972-75. Journal of Fisheries Research Board of Canada. 36:1145-1149.
{HYDROACOUSTICS, BIOMASS, ABUNDANCE ESTIMATES, SALMONIDS, FRESHWATER}

Thorne, R.E. 1983. Assessment of population abundance by hydroacoustics. Biological Oceanography 2:254-261.
{HYDROACOUSTICS, POPULATION, ABUNDANCE ESTIMATE}

Traynor, J.J., and J.E. Ehrenberg. 1979. Evaluation of the dual beam acoustic fish target strength measurement method. Journal of the Fisheries Research Board of Canada 1065-1071.
{HYDROACOUSTICS, DUAL-BEAM, METHODS}

Ulltang, 0. 1977. Methods of measuring stock abundance other than by use of commercial catch and effort data. Food and Agricultural Organization, United Nations, Fisheries Technical Paper No. 176. Rome, Italy. 23 pp.
{HYDROACOUSTICS, POPULATION, ABUNDANCE}

E. Total Biomass - Fish Standing Crop

Aggus, L.R., and S.A. Lewis. 1978. Environmental conditions and standing crop of fishes in predator-stocking-evaluation reservoirs. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 30:131-140.
[STANDING CROP, BIOMASS, FRESHWATER, ENVIRONMENTAL FACTORS]

Carlander, K.D. 1955. The standing crop of fish in lakes. Journal of the Fisheries Research Board of Canada 12:543-570.
[STANDING CROP, BIOMASS, FRESHWATER}

Carlander, K.D. 1977. Biomass, production, and yields of walleye (*Stizostedion vitreum vitreum*) and yellow perch (*Perca flavescens*) in North American Lakes. Journal of the Fisheries Research Board of Canada 34:1602-1612.
[STANDING CROP, BIOMASS, YIELD, FRESHWATER, PERCIDS, WALLEYES}

Eck, G.W., and E.H. Brown, Jr. 1985. Lake Michigan's capacity to support lake trout (*Salvelinus namaycush*) and other salmoinines: an estimate based on the status of prey populations in the 1970's. Canadian Journal of Fisheries and Aquatic Sciences 42:449-454.
{STANDING CROP, BIOMASS, PREY, SALMONIDS, GREAT LAKES}

Forney, J.L. 1967. Estimates of biomass and mortality rates in a walleye population. New York Fish and Game Journal 14:176-192.
[STANDING CROP, BIOMASS, MORTALITY, FRESHWATER, WALLEYES]

Forney, J.L. 1975. Abundance of larval walleye (*Stizostedion vitreum*) estimated from the catch in high-speed nets. Pages 581-588 *in* Symposium on the methodology for the survey, monitoring, and appraisal of fishery resources in lakes and large rivers. R.L. Welcomme, editor. EIFC (European Inland Fisheries Commission), FAO, UN, Technical Paper 23 (Supplement 1).
[STANDING CROP, ABUNDANCE ESTIMATES, FRESHWATER, LARVAL, WALLEYES]

Godabout, L., and R.H. Peters. 1988. Potential determinants of stable catch in the brook trout (*Salvelinus fontinalis*) sport fishery in Quebec. Canadian Journal of Fisheries and Aquatic Sciences 45:1771-1778.
[STANDING CROP, YIELD, PREDICTORS, FRESHWATER, SALMONIDS]

Hanson, J.M., and W.C. Leggett. 1982. Empirical prediction of fish biomass and yield. Canadian Journal of Fisheries and Aquatic Sciences 39:257-263.
[STANDING CROP, BIOMASS, YIELD, EMPIRICAL PREDICTIONS, FRESHWATER]

Hatch, R.W., P.M. Haack, and E.H. Brown, Jr. 1981. Estimates of alewife biomass in Lake Michigan, 1967-1978. Transactions of the American Fisheries Society 110:575-584.
[STANDING CROP, BIOMASS, TIME SERIES, ALEWIFE, GREAT LAKES]

Henderson, H.E., R.A. Ryder, and A.W. Kudhongania. 1973. Assessing fishery potentials of lakes and reservoirs. Journal of the Fisheries Research Board of Canada 30:2000-2009.
[STANDING CROP, STOCK ASSESSMENT, POTENTIAL, FISHERIES, FRESHWATER]

Jenkins, R.M. 1967. The influence of some environmental factors on standing crop and harvest of fishes in U.S. reservoirs. Pages 298-321 *in* G.E. Hall, editor. Reservoir fishery resources symposium. Southern Division, American Fisheries Society, Bethesda, Maryland, USA.
[STANDING CROP, YIELD, ENVIRONMENTAL FACTORS, FRESHWATER]

Jenkins, R.M. 1975. Black bass crops and species associations in reservoirs. Pages 114-124 *in* R.H. Stroud and H. Clepper, editors. Black bass biology and management. Sport Fishing Institute, Washington, District of Columbia, USA.
[STANDING CROP, SYNECOLOGY, FRESHWATER, CENTRARCHIDS]

Matuszek, J.E. 1978. Empirical predictions of fish yields of large North American lakes. Transactions of the American Fisheries Society 107: 385-394.
[STANDING CROP, YIELD, EMPIRICAL PREDICTION, FRESHWATER]

Newman, R.M., and F.B. Martin. 1983. Estimation of fish production rates and associated variances. Canadian Journal of Fisheries and Aquatic Sciences 40:1729-1736.
[STANDING CROP, BIOMASS, PRODUCTION, FRESHWATER, STATISTICS]

Ploskey, G.R., L.R. Aggus, W.M. Bivin, and R.M. Jenkins. 1986. Regression equations for predicting fish standing crop, angler use, and sport fish yield for United States reservoirs. U.S. Fish and Wildlife Service, Administrative Report No. 86-5: 92 pp.
[STANDING CROP, YIELD, EMPIRICAL PREDICTION, FRESHWATER]

Regier, B.A., A.J. Cordone, and R.A. Ryder. 1971. Total fish landings from fresh waters as a function of limnological variables, with special reference to lakes of east-central Africa. Food and Agricultural Organization of the United Nations, Fish Stock Assessment Working Paper 3, Rome, Italy.
[STANDING CROP, BIOMASS, EMPIRICAL PREDICTION, FRESHWATER, AFRICA]

Scheider, W., and P. Wallis. 1973. An alternate method of calculating the population density of monsters in Loch Ness. Limnology and Oceanography 18:343.
[STANDING CROP, BIOMASS, FRESHWATER, METHODS]

Sheldon, R.W., and S.R. Kerr. 1972. The population density of monsters in Loch Ness. Limnology and Oceanography 17:796-798.
[STANDING CROP, BIOMASS, FRESHWATER]

Toews, D.R., and J.S. Griffith. 1979. Empirical estimates of potential fish yield for the Lake Bangweulu system, Zambia, Central Africa. Transactions of the American Fisheries Society 108:241-252.
[STANDING CROP, BIOMASS, POTENTIAL YIELD, EMPIRICAL PREDICTION, FRESHWATER, AFRICA]

**F.** Community Structure - Species Composition and Relative Abundance

Adams, G.F., and C.H. Olver. 1977. Yield properties and structure of boreal percid communities. Journal of the Fisheries Research Board of Canada 34:1613-1625.
[SYNECOLOGY, YIELD, GREAT LAKES, PERCIDS]

Brown, E.H. Jr., R.L. Argyle, N.R. Payne, M.E. Holey. 1987. Yield and dynamics of destabilized chub (*Coregonus spp.*) populations in Lakes Michigan and Huron, 1950-84. 1987. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):371-383.
[SYNECOLOGY, RELATIVE ABUNDANCE, TIME SERIES, FOOD WEB, GREAT LAKES]

Christie, W.J., K.A. Scott, P.J. Sly, and R.H. Strus. 1987. Recent changes in the aquatic food web of eastern Lake Ontario. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):53-60.
[SYNECOLOGY, RELATIVE ABUNDANCE, FOOD WEB, GREAT LAKES]

Cohen, Y., and J.N. Stone. 1987. Multivariate time series analysis of the Canadian fisheries system in Lake Superior. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):171-181.

{SYNECOLOGY, RELATIVE ABUNDANCE, TIME SERIES, FOOD WEB, GREAT LAKES}

Daan, N. 1987. Multispecies versus single-species assessment of North Sea fish stocks. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):360-370.
{SYNECOLOGY, RELATIVE ABUNDANCE, FOOD WEB, MULTISPECIES, MARINE}

Dickie, L.M., S.R. Kerr, and P. Schwinghamer. 1987. An ecological approach to fisheries assessment. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):68-74.
[SYNECOLOGY, RELATIVE ABUNDANCE, FOOD WEB, ENVIRONMENTAL, FRESHWATER)

Evans, D.O., and P. Waring. 1987. Changes in the multispecies, winter angling fishery of Lake Simcoe, Ontario, 1961-83: invasion by rainbow smelt, Osmerus mordax, and the role *of* intra- and interspecific interactions. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):182-197.
{SYNECOLOGY, SPECIES COMPOSITION, RELATIVE ABUNDANCE, TIME SERIES, FOOD WEB, FISHERY, FRESHWATER]

Goddard, C.I., D.H. Loftus, J.A. MacLean, C.H. Oliver, and B.J. Shuter. 1987. Evaluation of the effects of fish community structure on observed yields of lake trout (*Salvelinus namaycush*). Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):239-248.
[SYNECOLOGY, RELATIVE ABUNDANCE, YIELD, FOOD WEB, FRESHWATER, SALMONIDS}

Le Cren, E.D. 1987. Perch (*Perca fluviatilis*) and pike (*Esox lucius*) in Windermere from 1940 to 1985: studies in population dynamics. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):216-228.
{SYNECOLOGY, RELATIVE ABUNDANCE, FOOD WEB, FRESHWATER, PERCIDS}

Loftus, D.H., C.H. Olver, E.H. Brown, P.J. Colby, W.L. Colby, W.H. Hartman, and D.H. Schupp. Partitioning potential fish yields from the Great Lakes. 1987. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):417-424.
[SYNECOLOGY, RELATIVE ABUNDANCE, SPECIES COMPOSITION, YIELD, POTENTIAL, FOOD WEB, GREAT LAKES]

MacCallum, W.R., and J.H. Selgeby. 1987. Lake Superior revisited 1984. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2): 23-

[SYNECOLOGY RELATIVE ABUNDANCE, FOOD WEB, FRESHWATER, GREAT LAKES}

Pimm, S.L., and J.B. Iiyman. 1987. Ecological stability in the context of multispecies fisheries. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):84-94.
{SYNECOLOGY, RELATIVE ABUNDANCE, FOOD WEB, MULTISPECIES, FRESHWATER)

Roberge, M.M., G. Low, and C.J. Reed. 1986. An assessment of the commercial fishery and population structure of walleye in Kakisa Lake, Northwest

Territories, 1977-1985. Canadian Technical Report of Fisheries and Aquatic Sciences, Number 1435.
~SYNECOLOGY, RELATIVE ABUNDANCE, FISHERIES, COMMERCIAL, FOOD WEB, FRESHWATER, WALLEYES]

Steedman, R.J., and H.A. Regier. 1987. Ecosystem science for the Great Lakes: perspectives on degradative and rehabilitative transformations. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):95-103.
[SYNECOLOGY, RELATIVE ABUNDANCE, FOOD WEB, GREAT LAKES}

Walters, C.J. 1987. Nonstationarity of production relationships in exploited populations. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):156-165.
[SYNECOLOGY, RELATIVE ABUNDANCE, EXPLOITATION, FOOD WEB, FRESHWATER}

## G. Size Structure - Species Length or Weight Composition [Proportional Stock Density (PSD) ]

Anderson, R.O. 1976. Management of small warm water impoundments. Fisheries (Bethesda, Maryland) 1(6):5-7, 26-27.
{SIZE STRUCTURE, FRESHWATER1

Anderson, R.O. 1978. New approaches to recreational fishery management. Pages 73-78 *in* G.D. Novinger and J.D. Dillard, editors. New approaches to the management of small impoundments. American Fisheries Society, North Central Division, Special Publication 5, Bethesda, Maryland.
{SIZE STRUCTURE, FRESHWATER, PSD}

Carline, R.F., B.L. Johnson, and T.J. Hall. 1984. Estimation and interpretation of proportional stock density for populations in Ohio Impoundments. North American Journal of Fisheries Management 4:139-154.
{SIZE STRUCTURE, FRESHWATER, PSD}

Carpenter, S.R., J.F. Kitchell, and J.R. Hodgson. 1985. Cascading trophic interactions and lake productivity. Bioscience 35:634-639.
{SIZE STRUCTURE, SYNECOLOGY, FRESHWATER]

Crowder, L.B., M.E. McDonnald, and J.A. Rice. 1987. Understanding recruitment of Lake Michigan fishes: the importance of size-based interactions between fish and zooplankton. Canadian Journal of Fisheries and Aquatic Sciences 44 (Supplement 2): 141-147.
{SIZE STRUCTURE, SYNECOLOGY, RECRUITNEXT, FRESHWATER]

Gabelhouse, D.W.,Jr. and D.W. Willis. 1986. Basis and utility of angler catch data for assessing size structure and density of largemouth bass. North American Journal of Fisheries Management 6:481-489.
{SIZE COMPOSITION, CREEL, STOCK DENSITY, FRESHWATER}

Gustafson, K.A. 1988. Approximating confidence intervals for indices of fish population size structure. North American Journal of Fisheries Management 8:139-141.
[SIZE STRUCTURE, STATISTICS, METHODS, PSD]

Macdonald, P.D.M., T.J. Pitcher. 1979. Age-groups from size-frequency data: a versatile and efficient method for analyzing distribution mixtures. Journal of the Fisheries Research Board of Canada 36: 987-1001.
[SIZE STRUCTURE, AGE, LENGTH-FREQUENCY, METHODS, COMPUTER PROGRAM, FRESHWATER]

McDonald, M.E., and A.E. Hershey. 1989. Size structure of a lake trout (*Savelinus namaycush*) population in an Artic lake: influence of angling and implications for fish community structure. Canadian Journal of Fisheries and Aquatic Sciences 46:2153-2156.
[SIZE STRUCTURE, SYNECOLOGY, GILL NET, EXPLOITATION, ANGLING, FRESEWATER, SALMONIDS]

Powell, T.C., D.C. Bowden, and H.K. Hagen. 1971. Evaluation of fishing gear in Boyd Reservoir, Colorado. Pages 313-320 *in* G.E. Hall, editor. Reservoir fisheries and limnology. Special Publication No. 8, American Fisheries Society, Washington, D.C.
[SIZE COMPOSITION, RELATIVE ABUNDANCE, METHODS, GILL NET, FRESHWATER]

Sheldon, R.W., A. Prakash, and W.H. Sutcliffe, Jr. 1972. The size distribution of particles in the ocean. Limnology and Oceanography 17:327-340.
[SIZE SPECTRUM, BIOMASS, MARINE]

Wege, G.J, and R.O. Anderson 1978. Relative weight ($W_r$): a new index of condition of largemouth bass. Pages 79-91 *in* G.D. Novinger and J.D. Dillard, editors. New approaches to the management of small impoundments. American Fisheries Society, North Central Division, Special Publication 5, Bethesda, Maryland.
[SIZE STRUCTURE, FRESHWATER, PSD]

Weithman, S.W., J.B. Reynolds, and D.E. Simpson. 1980. Assessment of the structure of largemouth bass stocks by sequential sampling. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 33:415-424.
[SIZE STRUCTURE, FRESHWATER, PSD]

Willis, D.W., K.D. McCloskey, and D.W. Gabelhouse, Jr. 1985. Calculation of stock density indices based on adjustment for efficiency of gill-net mesh size. North American Journal of Fisheries Management 5:126-127.
[SIZE STRUCTURE, LENGTH FREQUENCY, SAMPLING, GILL NET, MESH SIZE, METHODS, PSD]

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## II. Empirically Derived Indicators of Potential Fish Yield

### A. **Morphological**

{Area, volume, depth, or volume/area of whole lakes or of stratified layers; ratios of epilimnion to hypolimnion, mixed layer depths, rates of exchange or flow through (Leach et al. 1987).}

Neuman, J.G. 1978. Maximum depth and average depth of lakes. Journal of the Fisheries Research Board of Canada 16:923-927.
{MORPHOLOGY, DEPTH, FRESHWATER}

Hakanson, L. 1977. On lake form, lake volume, and lake hypsographic survey. Geography Annuls 59A: l-29.
{MORPHOLOGY, VOLUME, FRESHWATER}

Rawson, D.S. 1952. Mean depth and the fish production of large lakes. Ecology 33:513-521.
[POTENTIAL YIELD, EEPIRICAL PREDICTIONS, MORPHOLOGY, DEPTH, FRESHWATER}

Rawson, D.S. 1960. A limnological comparison of twelve large lakes in northern Saskatchewan. Limnology and Oceanography 5:195-211.
[POTENTIAL YIELD, EMPIRICAL PREDICTIONS, MORPHOLOGY, LIMNOLOGY, FRESHWATER}

Sakamoto, M. 1966. Primary production by phytoplankton community in some Japanese lakes and its dependence on lake depth. Archiv fur Hydrobiologie 62:1-28.
{PRIMARY PRODUCTION, EMPIRICAL PREDICTIONS, MORPHOLOGY, DEPTH, FRESHWATER]

### B. Physical and Chemical

(Nutrient concentration, dissolved gasses, transparency, total dissolved solids (TDS), temperature (Leach et al. 1987).}

(1) Nutrients, including "trophic" status

Bachmann, R.W., and J.R. Jones. 1974. Phosphorus inputs and algal blooms in lakes. Iowa State Journal of Research 49:155-160.
{PRIMARY PRODUCTION, EMPIRICAL PREDICTIONS, NUTRIENTS, ALGAE, FRESHWATER}

Brocksen, R.W., G.E. Davis, and C.E. Warren. 1970. Analysis of trophic processes on the basis of density dependent functions. Pages 468-498 *in* J.E. Steele, editor. Marine food chains. Oliver and Boyd, Edinburg, Scotland.
{TROPHIC STATE, DENSITY DEPENDENT, EMPIRICAL PREDICTIONS}

Canfield, D.E., Jr., K.A. Langeland, M.J. Maceina, W.T. Haller, J.V. Shireman, and J.R. Jones. 1983. Trophic state classification of lakes with aquatic

macrophytes. Canadian Journal of Fisheries and Aquatic Sciences 40:1713-1718.
{TROPHIC STATE, EMPIRICAL PREDICTIONS, MACROPHYTES}

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography 22:361-369.
{TROPHIC STATE, INDEX, EMPIRICAL PREDICTIONS}

Carlson, R.E. 1979. A review of the philosophy and construction of trophic state indices. Pages l-52 *in* Lake reservoir classification system. EPA 600/3-79-074. Corvallis Environmental Research Laboratory, Corvallis, OR.
{TROPHIC STATE, INDEX, EMPIRICAL PREDICTIONS, THEORY}

Dillon, P.J., and F. Rigler. 1974a. A test of the simple nutrient budget model predicting the phosphorous concentration in lake water. Journal *of* the Fisheries Research Board of Canada 31:1771-1778.
{TROPHIC STATE, NUTRIENTS, EMPIRICAL PREDICTIONS]

Dillon, P.J., and F. Rigler. 1974b. The phosphorous-chlorophyll relationships in lakes. Limnology and Oceanography 19:767-773.
{TROPHIC STATE, NUTRIENTS, CHLOROPHYLL, MPIRICAL PREDICTIONS}

Gascon, D., and W.C. Leggett. 1977. Distribution, abundance, and resource utilization of littoral zone fishes in response to a nutrient/production gradient in Lake Memphremagog. Journal of the Fisheries Research Board of Canada 34:1105-1117.
{SYNECOLOGY, NUTRIENTS, CHLOROPHYLL, EMPIRICAL PREDICTIONS]

Hanson, J.M., and W.C. Leggett. 1982. Empirical prediction of fish biomass and yield. Canadian Journal of Fisheries and Aquatic Sciences 39:257-263.
{TROPHIC STATE, BIOMASS, YIELD, NUTRIENTS, MACROBENTHOS, DEPTH, EMPIRICAL PREDICTIONS]

Jones, J.R., and R.W. Bachmann. 1976. Prediction of phosphorous and cholorophyll levels in lakes. Journal of the Water Pollution Control Federation 48:2176-2182.
{TROPHIC STATE, NUTRIENTS, CHLOYOPHYLL, EMPIRICAL PREDICTIONS}

Jones, J.R., and R.W. Bachmann. 1978. Trophic status of Iowa lakes in relation to origin and glacial geology. Hydrobiologia 57:267-273.
{TROPHIC STATE, NUTRIENTS, HORPEOLOGY, GEOLOGY}

Kratxer, C.R., and P.L. Brezonik. 1981. A Carlson-type trophic state index for nitrogen in Florida lakes. Water Resources Bulletin 17:713-715.
{TROPHIC STATE, NUTRIENTS, EMPIRICAL PREDICTIONS}

Moyle, J.B. 1956. Relationship between the chemistry of Minnesota surface waters and wildlife management. Journal of Wildlife Management 20:303-320.
{TROPHIC STATE, NUTRIENTS, EMPIRICAL PREDICTIONS}

Osgood, R.A. 1982. Using differences among Carlson's trophic state index values in regional water quality assessment. Water Resources Bulletin 18:67-74.
[TROPHIC STATE, INDEX, NUTRIENTS, EMPIRICAL PREDICTIONS]

Porcella, D.B., S.A. Petersen, and D.P. Larsen. 1979. Proposed method for evaluating the effects of restoring lakes. Pages 265-310 in S.A. Peterson, editor. Limnological and socioeconomic evaluation of lake restoration projects: approaches and preliminary results. EPA-600-3/79-005. Corvallis Environmental Research Laboratory, Corvallis, Oregon.
[TROPHIC STATE, NUTRIENTS, EMPIRICAL PREDICTIONS]

Rigler, R.A. 1975. The concept of energy flow and nutrient flow between trophic levels. Pages 15-26 in W.H. Van Dobben and R.H. Lowe-McConnell, editors. Unifying concepts in ecology. W. Junk, The Hague, The Netherlands.
[TROPHIC STATE, NUTRIENTS, EMPIRICAL PREDICTIONS]

Smith, V.H. 1979. Nutrient dependence of primary productivity in lakes. Limnology and Oceanography 24:1051-1064.
[TROPHIC STATE, PRIMARY PRODUCTIVITY, NUTRIENTS, EMPIRICAL PREDICTIONS]

Smith, V.H. 1982. The nitrogen and phosphorous dependence of algal biomass in lakes: an empirical and theoretical analysis. Limnology and Oceanography 27:1101-1112.
[TROPHIC STATE, PRIMARY PRODUCTIVITY, NUTRIENTS, EMPIRICAL PREDICTIONS]

(2) Oxygen

Charlton, M.N. 1980. Hypolimnion oxygen consumption in lakes: discussion of productivity and morphometry effects. Canadian Journal of Fisheries and Aquatic Sciences 37:1531-1539.
[TROPHIC STATS, OXYGEN, PRIMARY PRODUCTIVITY, NUTRIENTS, MORPHOLOGY]

Cornett, R.J., and F.H. Rigler. 1979. Hypolimnetic oxygen deficits: their production and interpretation. Science (Washington, District of Columbia) 205:580-581.
[TROPHIC STATE, OXYGEN, PRIMARY PRODUCTIVITY]

Hutchinson, G.E. 1938. On the relation between the oxygen deficit and the productivity and typology of lakes. Internationale Revue der Gesamten Hydrohiologie 36:336-355.
[TROPHIC STATE, OXYGEN, PRIMARY PRODUCTIVITY]

Walker, W.W. Jr. 1979. Use of hypolimnetic oxygen depletion rate as a trophic state index for lakes. Water Resources Research 17:1463-1470.
[TROPHIC STATE, OXYGEN, PRIMARY PRODUCTIVITY]

(3) Climate and Water Temperature

Christie, G.C. 1986. Masures of optimal thermal habitat and their relationships to yields for four commercial fish species. Master's Thesis, University of Toronto, Totonto, Ontario. 182 p.
{TEMPERATURE, HABITAT, MORPHOEDAPHIC INDEX, YIELD, FRESHWATER, WALLEYES}

Christie, G.C., and H.A. Regier. 1988. Measures of optimal thermal habitat and their relationship to yields for four commercial fish species. Canadian Journal of Fisheries and Aquatic Sciences 45:301-314.
{TEMPERATURE, HABITAT, MORPHOEDAPHIC INDEX, YIELD, FRESHWATER, WALLEYES}

Magnuson, J.J., L.B. Crowder, and P.A. Medvick. 1979. Temperature as an ecological resource. American Zoologist 19:331-343.
{TEMPERATURE, HABITAT}

Schlesinger, and A.M. McCombie. 1983. An evaluation of climate, morphoedaphic index and effort data as predictors of yields from Ontario sport fisheries. Ontario Fisheries Technical Report Series 10:14 p.
{CLIMATE, MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION}

Schlesinger, D.A., and H.A. Regier. 1982. Climatic and morphoedaphic indices *of* fish yields from natural lakes. Transactions of the American Fisheries Society 111:141-150.
{CLIMATE, MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION]

Schlesinger, D.A., and H.A. Regier. 1983. Relationship between environmental temperature and yields of subarctic and temperate zone fish species. Canadian Journal of Fisheries and Aquatic Sciences 40: 1829-1837.
{TEMPERATURE, YIELD, EMPIRICAL PREDICTION}

C. Biological

{Chlorophyll a or other pigment concentration, particulate organic matter (POM), living organic matter (ATP fraction of POM), dissolved organic matter (DOM), indices of diversity or community structure (Leach et al. (1987).}

Dickie, L.M. 1973. Interaction between fishery management and environmental production. Journal of the Fisheries Research Board of Canada 30:2496-2506.
{FISHERIES, MANAGEMENT, PRODUCTIVITY}

Ganf, G.G. 1974. Incidental solar irradiance and underwater light penetration as factors controlling the chlorophyll a content of a shallow equatorial lake (Lake George, Uganda) Journal of Ecology 62:593-609.
{PRIMARY PRODUCTIVITY, LIGHT, CHLOROPHYLL}

Iirbacek, J. 1969. Relations of biological productivity to fish production and the maintenance of water quality. Pages 298-321 in L. Obeng, editor. Man-made lakes, the Accra symposium, Ghana University Press, Accra, Ghana.
{PRIMARY PRODUCTIVITY, FISH PRODUCTION, WATER QUALITY}

Jones, J.R., and M.V. Hoyer. 1982. Sportfish harvest predicted by summer chlorophyll-a concentration in midwestern lakes and reservoirs. Transactions of the American Fisheries Society 112: 176-179. [STANDING CROP, YIELD, PRINARY PRODUCTIVITY, CHLOROPHYLL]

Kalff, J., and R. Knoechel. 1978. Phytoplankton and their dynamics in oligotrophic and eutrophic lakes. Annual Review of Ecology and Systematics 9:475-495. [TROPHIC STATE, PRIMARY PRODUCTIVITY, WATER QUALITY]

McCauley, E., and J. Kalff. 1981. Empirical relationships between phytoplankton and zooplankton biomass in lakes. Canadian Journal of Fisheries and Aquatic Sciences 38:458-463. [PRIMARY PRODUCTIVITY, ZOOPLANKTON, EMPIRICAL PREDICTION]

McConnell, W.J., S. Lewis, and J.E. Olson. 1977. Gross photosynthesis as an estimator of potential fish production. Transactions of the American Fisheries Society 106:417-423. [PRIMARY PRODUCTIVITY, POTENTIAL PRODUCTION, EMPIRICAL PREDICTION]

Melack, J.M. 1976. Primary productivity and fish yields in tropical lakes. Transactions of the American Fisheries Society 105:575-580. [PRIMARY PRODUCTIVITY, POTENTIAL YIELD, EMPIRICAL PREDICTION]

Mills, E.L., and A. Schiavone, Jr. 1982. Evaluation of fish communities through assessment of zooplankton populations and measures of lake productivity. North American Journal of Fisheries Management 2:14-27. [TROPHIC STATE, SYNECOLOGY, PRIMARY PRODUCTIVITY, ZOOPLANKTON, EMPIRICAL PREDICTION]

Northcote, T.G., and P.A. Larkin. 1956. Indices of productivity in British Columbia lakes. Journal of the Fisheries Research Board of Canada 13:515-540. [TROPHIC STATE, INDEX, PRODUCTIVITY, EMPIRICAL PREDICTION]

Oglesby, R.T. 1977. Relationship of fish yield to lake phytoplankton standing crop, production and morphoedaphic factors. Journal of the Fisheries Research Board of Canada 34:2271-2279. [TROPHIC STATE, STANDING CROP, PRIMARY PRODUCTIVITY, YIELD, EMPIRICAL PREDICTION]

Oglesby, R.T., J.H. Leach, and J. Forney. 1987. Potential *Stizostedion* yield as a function of chlorophyll concentration with special reference to Lake Erie. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):166-170. [STANDING CROP, POTENTIAL YIELD, CHLOROPHYLL, EMPIRICAL PREDICTION, WALLEYES]

Patalas, K. 1972. Crustacean plankton and the eutrophication of St. Lawrence Great Lakes. Journal of the Fisheries Research Board of Canada 29:1451-1462.

{TROPHIC STATE, ZOOPLANKTON, EMPIRICAL PREDICTION]

D. Derived Ratios

(Various ratios are derived from combinations of morphological and other indicators into what is referred to as morphoedaphic indices (MEI) (Leach et al. (1987) .}

Paulik, G.J., and D.S. Robson. 1969. Statistical calculations for change-in-ratio estimators of population parameters. Journal of Wildlife Management 33:1-27.
{RATIO, EMPIRICAL PREDICTION, STATISTICS]

(1) Morpho Edaphic Index (MEI)

Henderson, H.E., and R.L. Welcomme. 1974. The relationship of yield to morphoedaphic index and numbers of fishermen in African inland fisheries. CIFA (Committee for Inland Fisheries of Africa) Occasional Paper 1, Food and Agricultural Organization of the United Nations, Rome, Italy.
{MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION]

Jenkins, R.M. 1982. The morphoedaphic index and reservoir fish production. Transactions of the American Fisheries Society 111:133-140.
{MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION]

Kerr, S.R. 1982. The role of external analysis in fisheries science. Transactions of the American Fisheries Society 111:165-170.
{MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION]

Leach, J.H., L.M. Dickie, B.J. Shuter, U. Borgeman, J. Hyman, and W. Lysack. 1987. A review of the methods for prediction of potential fish production with application to the Graet Lakes and Lake Winnipeg. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):471-485.
{MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION]

Oglesby, R.T., editor. 1982. Special Section: The morphoedaphic index - concepts and practices. Transactions of the American Fisheries Society 111:133-175.
{MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION]

Oglesby, R.T. 1982. The ME1 symposium - overview and observations. Transactions of the American Fisheries Society 111:171-175.
{MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION]

Rigler, F.H. 1982. The relation between fisheries management and limnology. Transactions of the American Fisheries Society 111:121-132.
{MORPHOEDAPHIC INDEX, POTENTIAL, EWIRICAL PREDICTION]

Ryder, R.A. 1982. The morphoedaphic index - use, abuse, and fundamental concepts. Transactions of the American Fisheries Society 111:154-164.
{MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION}

Ryder, R.A. 1965. A method for estimating the potential fish production of north temperate lakes. Transactions of the American Fisheries Society 94:214-218.
{MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION}

Ryder, R.A., and H.F. Henderson. 1975. Estimates of potential yield for the Nasser Reservoir, Arab Rerublic of Egypt. Journal of the Fisheries Research Board of Canada 32:2137-2151.
{MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION]

Ryder, R.A., S.R. Kerr, K.H. Loftus, and H.A. Regier. 1974. The morphoedaphic index, a fish yield estimator - review and evaluation. Journal of the Fisheries Research Board of Canada 31:663-688.
{MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION}

SPOF. 1982. Partitioning yields estimated from the morphoedaphic index into individual species yields. Report to SPOF (Strategic Planning for Ontario Fisheries) Working Group No. 12, Ministry of Natural Resources, Ontario. 71 p.
{MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION}

Youngs, W.D., and D.G. Heimbuch. 1982. Another consideration of the morphoedaphic index. Transactions of the American Fisheries Society 111:151-153.
{MORPHOEDAPHIC INDEX, POTENTIAL YIELD, EMPIRICAL PREDICTION]

APPENDIX A-3. Results of "Predation Index" questionnaire.

PREDATION INDEXING - QUESTIONNIARE

*LIST OF PERSONS CONTACTED*

PRIMARY CONTACTS

RM/WBE TWG:

Ron Boyce, ODFW
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PREDATION INDEXING - QUESTIONNAIRE

INSTRUCTIONS

From: Steven Vigg
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Subject: Expert consultation on predation problem in Columbia River. (Please return questionnaire in one week: contact me if you have any questions or points in need of clarification.1

You have been recommended by a RM/WBE TWG committee member as a person with knowledge and experience in Columbia River fisheries problems relevant to smolt mortality in reservoirs and river reaches. I am seeking your input on areas in the Columbia River Basin which have significant losses of juvenile salmonids due to northern squawfish predation. One objective of the ongoing Predator-Prey Project 82-012 is developing a predator abundance & predation index. We are looking at the feasibility various methods of predator abundance indexing (e.g., cpue, mortality per river mile, habitat, MEI, hydroacoustics); one method is expert consensus (e.g., workshops, and the Delphi technique). Please fill out the following table which is intended to help address the question of which areas are the "predation hotspots" in the Columbia Basin. Data derived from the questionnaire will be reported in summary tables and the individual responses will remain anonymous.

Note: (1) The reservoir areas are listed by Project and site; i.e., "The Dalles T" refers to The Dalles Dam Tailrace; (2) The only predator this questionnaire refers to is northern squawfish; (3) the only prey this questionnaire refers to is migratory juvenile salmonids -- "smolts"; e.g. Hells Canyon Reservoir may have resident 0. *mykiss* juveniles but this questionnaire is not concerned with their losses.

Scoring:
0= not present
l= very low
2= low
3= medium
4= high
5= very high

| Scoring Example: | A. Predator Abundance | | B. Smolt Abundance | | LOSS = A*B |
|---|---|---|---|---|---|
| F.D.Roosevelt R. | 4 | * | 0 | = | 0 |
| Reservoir X | 3 | * | 3 | = | 9 |

Circle up to 5 specific "hotspots", where you think the worst predation problem in the Columbia River Basin exists.

For Example: 12. Wells T
F
R

## PREDATION INDEX RESULTS - OVERALL MEAN SCORES

| Project or Reach Number | Area* (F,R,T/ (reach) | Percent Responce with data (n= 26) | Mean Predation Score: A. Predator Abundance | B. Smolt Abundance | LOSS | "Hot-spot " (n) |
|---|---|---|---|---|---|---|
| A. LOWER COLUMBIA RIVER: | | | | | | |
| 1. Estuary | L | 50.0 | 2.2 | 4.6 | 10.1 | 0 |
| | M | 50.0 | 2.5 | 4.6 | 11.7 | 0 |
| | U | 46.2 | 2.8 | 4.6 | 12.4 | 0 |
| 2.Bonneville1 | T | 65.4 | 4.7 | 4.8 | 22.8 | 8 |
| | F | 73.1 | 4.7 | 4.8 | 22.6 | 10 |
| | R | 53.8 | 3.4 | 4.1 | 14.0 | 2 |
| 3.Bonneville2 | T | 65.4 | 4.2 | 4.1 | 17.5 | 4 |
| | F | 61.5 | 4.1 | 4.1 | 16.9 | 2 |
| 4. The Dalles | T | 50.0 | 4.0 | 4.0 | 15.9 | 3 |
| | F | 50.0 | 3.9 | 4.0 | 15.2 | 3 |
| | R | 50.0 | 3.2 | 3.5 | 10.9 | 1 |
| 5. John Bay | T | 65.4 | 4.2 | 4.1 | 17.2 | 2 |
| | F | 76.9 | 4.4 | 4.1 | 17.9 | 4 |
| | R | 73.1 | 3.9 | 3.6 | 14.6 | 4 |
| 6. McNary | T | 73.1 | 4.5 | 4.1 | 18.8 | 9 |
| | F | 65.4 | 4.1 | 4.4 | 18.5 | 4 |
| | R | 61.5 | 3.6 | 3.7 | 13.8 | 2 |
| MID-COLUMBIA RIVER: | | | | | | |
| 7. Hanford Reach | L | 50.0 | 2.5 | 3.4 | 8.8 | 0 |
| | M | 50.0 | 2.4 | 3.4 | 8.3 | 0 |
| | u | 50.0 | 2.6 | 3.6 | 9.4 | 0 |

PREDATION INDEX RESULTS (Continued)

| Project or Reach Number | Area* (F,R,T/ (reach) | Percent Responce with data (n= 26) | Mean Predation Score: A. Predator Abundance | Mean Predation Score: B. Smolt Abundance | Loss | "Hot-spot" (n) |
|---|---|---|---|---|---|---|
| 8. Priest Rapids | T | 42.3 | 3.2 | 3.7 | 12.2 | 1 |
| | F | 42.3 | 2.7 | 3.7 | 10.5 | 1 |
| | R | 42.3 | 2.4 | 3.1 | 7.4 | 1 |
| 9. Wanapum | T | 42.3 | 3.1 | 3.6 | 11.5 | 0 |
| | F | 42.3 | 2.6 | 3.5 | 9.3 | 0 |
| | R | 42.3 | 2.5 | 2.9 | 7.1 | 0 |
| 10. Rock Island | T | 42.3 | 2.8 | 3.6 | 10.5 | 0 |
| | F | 42.3 | 2.5 | 3.5 | 8.8 | 0 |
| | R | 42.3 | 2.3 | 2.8 | 6.6 | 0 |
| 11. Rocky Reach | T | 42.3 | 2.7 | 2.8 | 8.2 | 0 |
| | F | 42.3 | 2.4 | 2.7 | 6.8 | 0 |
| | R | 42.3 | 2.1 | 2.2 | 4.6 | 0 |
| 12. Wells | T | 42.3 | 2.5 | 2.5 | 6.6 | 1 |
| | F | 42.3 | 2.3 | 2.5 | 6.2 | 1 |
| | R | 38.5 | 2.0 | 1.9 | 3.9 | 0 |
| LOWER SNAKE RIVER: | | | | | | |
| 13. Ice Harbor | T | 50.7 | 3.7 | 3.1 | 12.3 | 3 |
| | F | 50.0 | 3.3 | 3.0 | 10.4 | 1 |
| | R | 50.0 | 2.8 | 2.6 | 7.5 | 1 |
| 14. Lower Monument al | T | 42.3 | 3.3 | 3.0 | 10.2 | 0 |
| | F | 42.3 | 3.1 | 3.0 | 9.7 | 0 |
| | R | 46.2 | 2.8 | 2.7 | 1.7 | 0 |

PREDATION INDEX RESULTS (Continued)

| Project or Reach Number | Area* (F,R,T/ (reach) | Percent Responce with data (n= 26) | Mean Predation Score: A. Predator Abundance | B. Smolt Abundance | Loss | "Hot-spot" (n) |
|---|---|---|---|---|---|---|
| 15. Little Goose | T | 53.8 | 3.4 | 2.7 | 9.8 | 0 |
| | F | 50.0 | 3.2 | 3.1 | 10.6 | 0 |
| | R | 50.0 | 2.7 | 2.7 | 7.5 | 0 |
| 16. Lower Granite | T | 50.0 | 3.2 | 2.9 | 9.9 | 1 |
| | F | 50.0 | 3.2 | 3.9 | 13.5 | 1 |
| | R | 50.0 | 2.8 | 3.4 | 10.2 | 1 |
| 17. Open River | L | 42.3 | 2.1 | 3.0 | 6.6 | 0 |
| | M | 42.3 | 2.0 | 2.6 | 5.3 | 0 |
| | U | 42.3 | 2.0 | 2.4 | 4.8 | 0 |
| 18. Hells Canyon Tailrace | L | 38.5 | 2.0 | 1.7 | 3.6 | 0 |
| | M | 38.5 | 2.0 | 1.6 | 3.4 | 0 |
| | U | 38.5 | 2.1 | 1.5 | 3.4 | 0 |

* Area codes:

T= tailrace, project
F= forebay, project
R= reservoir, project
L= lower reach, open river
M= mid reach, open river
U= upper reach, open river

APPENDIX A-4. Selected bibliography on habitat indices as predictors of fish production.
[Instream Flow Incremental Methodology (IFIM), Habitat Evaluation Procedures (HEP), Habitat Suitability Index (HSI)]

Aggus, L.R., and W.M. Bivin. 1982. Babitat suitability index models: regression models based on harvest of coolwater and coldwater fishes in reservoirs. U.S. Fish and Wildlife Service, FWS/OBS-82/10.25, Washington, D.C., USA.
{HABITAT, HSI, MODELS, HARVEST}

Aho, J.M., C.S. Anderson, and J.W. Terrell. 1986. Habitat suitability index models and instream flow suitability curves: redbreast sunfish. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.60, Washington, D.C.
{HABITAT, HSI, MODELS, REDBREAST SUNFISH}

Armantrout, N.B. 1981. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.
{HABITAT, INVENTORY}

Armour, C.L., R.J. Fisher, and J.W. Terrell. 1984. Comparison of the use of the Habitat Evaluation Procedures (HEP) and the Instream Flow Incremental Methodology (IFIM) in aquatic analyses. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-84/11 , Washington, D.C. 30 pp.
{HABITAT, HEP, IFIM, MODELS, METHODS}

Bain, M.B., and J.L. Bain. 1982. Habitat suitability index models: coastal stocks of striped bass. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.1, Washington, D.C.
{HABITAT, HSI, MODELS, MARINE, ANADROMOUS, STRIPED BASS}

Bain, M.B., J.T. Finn, L.J. Gerardi, Jr., M.R. Ross, and W.P. Saunders, Jr. 1982. An evaluation of methodologies for assessing the effects of flow fluctuations on stream fish. Massachusets Cooperative Fishery Research Unit, Contract USDI 14-16-0009-80-1003, Project Completion Report, Amherst.
{HABITAT, FLOW, IFIH, HSI, METHODS, MODELS)

Binns, N.A., and F.M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society 108:215-228.
{HABITAT, QUALITY INDEX, TROUT}

Boussu, M.F. 1954. Relationships between trout populations and cover on a small stream. Journal of Wildlife Management 18:229-239.
{HABITAT, COVER, STANDING CROP, TROUT}

Bovee, K.D. 1978. Probability-of-use criteria for the family Salmonidae. U.S. Fish and Wildlife Service, Instream Flow Information Paper 4, FWS/OBS-78/07.
{HABITAT, FLOW, ISIM, MODELS, METHODS, SALMONIDS}

Bovee, K.D. 1982. A guide to stream habitat analysis using instream flow incremental methodology. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-82/26.
{HABITAT, FLOW, ISIH, MODELS, METHODS}

Bovee, K.D., and T. Cochnauer. 1977. Development and evaluation of weighted criteria, probability-of-use curves for instream flow assessments:fisheries. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-77/63.
{HABITAT, mow, ISIM, MODELS, METHODS}

Bovee, K.D., and R.T. Milhous. 1978. Hydraulic simulation in instream flow studies: theories and techniques. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-78/33.
{HABITAT, FLOW, ISIM, MODELS, METHODS}

Bowlbey, J.N., and J.C. Roff. 1986. Trout biomass and habitat relationships in southern Ontario streams. Transactions of the American Fisheries Society 115:503-514.
{HABITAT, QUALITY INDEX, TROUT)

Buckley, J. 1984. Habitat suitability index models: larval and juvenile red drum. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.74, Washington, D.C.
{HABITAT, HSI, MODELS, RED DRUM}

Burton, R.A., and T.A. Wesche. 1974. Relationships of duration of flows and selected watershed parameters to the standing crop estimates of trout populations. University of Wyoming. Water Resources Research Institute, Water Resources Series Number 52, Laramie.
IHABITAT, FLOW, MODELS, TROUT}

Chapman, D.W. 1966. Food and space as regulators of salmonid populations in streams. American Naturalist 100:345-357.
(HABITAT, ECOLOGY, FRESHWATER, STREAMS, SALMONIDS}

Chapman, D.W., and E. Knudsen. 1980. Channelization and livestock impact on salmonid habitat and biomass in western Washington. Transactions of the American Fisheries Society 109:357-363.
{HABITAT, FLOW, BIOMASS, SALMONIDS}

Christmas, J.Y., J.T. McBee, R.S. Waller, and F.C. Sutter III. 1982. Habitat suitability index models: gulf menhaden. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.23, Washington, D.C.
[HABITAT, HSI, MODELS, GULF MENHADEN}

Crance, J.H. 1984. Habitat suitability index models and instream flow suitability curves: inland stocks of striped bass. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.85, Washington, D.C.
[HABITAT, BSI, MODELS, FRESHWATER, STRIPED BASS}

Crance, J.H. 1985. Delphi technique procedures used to develop habitat suitability index models and instream flow suitability curves for inland stocks of striped bass. U.S. Fish and Wildlife Service, Western Energy and Land Use Team WELUT-85/w07, Fort Collins, Colorado.
{HABITAT, HSI, MODELS, DELPHI, FRESHWATER, STRIPED BASS}

Crance, J.H. 1986. Habitat suitability index models and instream flow suitability curves: shortnose sturgeon. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/129, Washington, D.C.
{HABITAT, HSI, MODELS, SHORTNOSE STURGEON)

Crance, J.H. 1987. Habitat suitability index curves for paddlefish, developed by the Delphi technique. North American Journal of Fisheries Management 7:123-130.
{HABITAT, HSI, MODELS, DELPHI, PADDLEFISH}

Devore, P.W, and R.J. White. 1978. Daytime responses of brown trout (*Salmo trutta*) to cover stimuli in stream channels. Transactions of the American Fisheries Society 107:763-771.
{HABITAT, COWER, STANDING CROP, TROUT}

Edwards, E.A. 1983a. Habitat suitability index models: bigmouth buffalo. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.34, Washington, D.C.
{HABITAT, HSI, MODELS, BIGMOUTH BUFFALO}

Edwards, E.A. 1983b. Habitat suitability index models: longnose sucker. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.35, Washington, D.C.
(HABITAT, HSI, MODELS, LONGNOSE SUCKER}

Edwards, B.A., M. Bacteller, and O.E. Maughan. 1982. Habitat suitability index models: slough darter. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.9, Washington, D.C.
{HABITAT, HSI, MODELS, SLOUGH DARTER}

Edwards, E.A., G. Gebhart, and O.E. Maughan. 1983. Habitat suitability information: smallmouth bass. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.36, Washington, D.C.
[HABITAT, HSI, MODELS, SNALLMOUTE BASS}

Edwards, E.A., H. Li, and C.B. Schreck. 1983. Habitat suitability index models: longnose dace. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.33, Washington, D.C.
(HABITAT, HSI, MODELS, LONGNOSE DACE}

Edwards, E.A., and K. Twomey. 1982a. Habitat suitability index models: common carp. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-84/11 , Washington, D.C.
{HABITAT, HSI, MODELS, CARP}

Edwards, E.A., and K. Twomey. 1982b. Habitat suitability index models: smallmouth buffalo. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.13, Washington, D.C.
{HABITAT, HSI, HODELS, SMALLMOUTH BUFFALO)

Eifert, W.H., and T.A. Wesche. 1982. Evaluation of the stream reach inventory and channel stability index for instream habitat analysis. University of Wyoming, Water Resources Research Institute, Water Resources Series Number 82, Laramie.
{HABITAT, INDEX, MODELS1

Flather, C.H., and T.W. Hoekstra. 1985. Evaluating population habitat models using ecological theory. Wildlife Society Bulletin 13: 121-130.
[HABITAT, HSI, HODELS, THEORY)

Glova, G.J. 1982. Fishery impact evaluation -- application of the incremental method. Pages 16-27 in R.H.S. McColl, editor. River low flows: conflicts of water use. New Zealand Ministry of Works and Development, Water and soil Miscellaneous Publication 47, Wellington.
{HABITAT, FLOW, ISIM, NODELS, METHODS)

Green, R.H. 1971. A multivariate statistical approach to the Hutchinsonian niche: bivalve molluscs of central Canada. Ecology 52:543-556.
{HABITAT, EMPIRICAL, STATISTICAL, MULTIVARIATE, MODELS}

Grenney, W.J., and A.K. Krassewski. 1981. Description and application of the stream simulation and assessment mode: Version IV (SSAM IV). U.S. Fish and Wildlife Service, Instream Flow Information Paper 17, FWS/OBS-81/46.
IHABITAT, FLOW, ISIM, HODELS, METHODS}

Hale, S.S., T.E. McMahon, and P.C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: chum salmon. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-84/11 , Washington, D.C.
{HABITAT, HSI, MODELS, CHUM SALMON)

Hamilton, K. and P.C. Nelson. 1984. Habitat suitability index models and instream flow suitability curves: white bass. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.89, Washington, D.C.
{HABITAT, HSI, MODELS, WHITE BASS}

Heller, D.A., J.R. Maxwell, and M. Parsons. 1983. Modeling the effects of forest management on salmonid habitat. U.S. Forest Service, Suislaw National Forest, Gresham Oregon.
(HABITAT, MODELS, FOREST, SALMONIDS}

Hodgetts, R.M. 1977. Applying the Delphi technique to management gaming. Simulation 29:209-212.
{HABITAT, MODELS, TEEORY, DELPHI)

Hubert, W.A., S.H. Anderson, P.D. Southall, and J.H. Crance. 1984. Habitat suitability index models: paddlefish. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.80, Washington, D.C.

(HABITAT, HSI, MODELS, PADDLEFISH}

Hubert, W.A., R.S. Helzner, L.A. Lee, and P.C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: artic grayling riverine populations. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.110, Washington, D.C.
{HABITAT, HSI, MODELS, ARTIC GRAYLING}

Inskip, P.D. 1982. Habitat suitability index models: northern pike. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-84/10.17, Washington, D.C.
(HABITAT, HSI, MODELS, NORTHERN PIKE}

Kostecki, P.T. 1984. Habitat suitability index models: spotted sea trout. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.75, Washington, D.C.
{HABITAT, HSI, MODELS, SPOTTED SEA TROUT}

Krenkle, P.A., G.F. Lee, and R.A. Jones. 1979. Effects of TVA impoundments on downstream water quality and biota. Pages 289-306 *in* J.V. Ward and J.A. Stanford, editors. The ecology of regulated streams. Plenum, New York.
{HABITAT, FLOW, RESERVOIRS}

Krieger,D.A., J.W. Terrell, and P.C. Nelson. 1983. Habitat suitability information: yellow perch. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.55, Washington, D.C.
[HABITAT, BSI, MODELS, YELLOW PERCH}

Larimore, R.W., and D.D. Garrels. 1985. Assessing habitats used by warmwater stream fishes. Fisheries (Bethesda) 10(2):10-16.
{HABITAT, MODELS, WARMWATER STREAM}

Layher, W.G. 1983. Habitat suitability for selected adult fishes in prairie streams. Doctoral dissertation. Oklahoma State University, Stillwater.
{HABITAT, HSI, MODELS, WARMWATER STREAM}

Layher, W.G. 1985. Use of empirically derived habitat suitability curves to determine potential impacts of a small hydropower development. Pages 201-206 *in* F.W. Olson, R.G. White, and R.H. Hamre, editors. Symposium on small hydropower and fisheries. American Fisheries Society, Bethesda, Maryland.
{HABITAT, HSI, MODELS, HYDROPOWER}

Layher, W.G., and O.E. Maughan. 1981. Analysis and refinement of habitat evaluation procedures for eight warm-water fish species. Oklahoma Cooperative Fishery Research Unit, Project Completion Report, Stillwater, OK, USA
[HABITAT, BEP, MODELS, METHODS}

Layher, W.G., and O.E. Maughan. 1983. Utilization of the SAS computer system to model the ahiotic niche of the central stoneroller in prairie streams. Transactions of the Kansas Academy of Science 2:16.

{HABITAT, HSI, MODELS, CENTRAL STONEROLLER}

Layher, W.G., and O.E. Maughan. 1984. Analysis and refinement of habitat suitability index models for eight warm-water fish species. Pages 182-250 in J.W. Terrell, editor. Proceedings of a workshop on fish habitat suitability index models. U.S. Fish and Wildlife Service Biological Report 85(6), Washington, D.C., USA
{HABITAT, HSI, MODELS, WARMWATER, STREAMS}

Layher, W.G., and O.E. Maughan. 1985a. Relations between habitat variables and channel catfish populations in prairie streams. Transactions of the American Fisheries Society 114:771-781.
{HABITAT, HSI, MODELS, CHANNEL CATFISH}

Layher, W.G., and O.E. Maughan. 1985b. Spotted bass habitat evaluation using an unweighted geometric mean to determine habitat suitability values. Proceedings of the Oklahoma Academy of Science 65:11-18.
{HABITAT, HSI, MODELS, METHODS, SPOTTED BASS}

Layher, W.G., and O.E. Maughan, and W.D. Warde. 1982. Utilizing the SAS computer system for modeling habitat suitability for warmwater fishes in streams. Pages 355-361 in N.B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. Western Division, American Fisheries Society, Bethesda, MD, USA
{HABITAT, HSI, MODELS, WARMWATER, STREAMS}

Layher, W.G., O.E. Maughan, and W.D. Warde. 1987. Spotted bass habitat suitability related to fish occurrence and biomass and measurements of physiochemical variables. North American Journal of Fisheries Management 7:238-251.
{HABITAT, ESI, MODELS, SPOTTED BASS)

Lewis, S.L., 1969. Physical factors influencing fish populations in pools of a trout stream. Transactions of the American Fisheries Society 98:14-22.
{HABITAT, PHYSICAL, STREAM, TROUT}

Li, H.W., C.B. Schreck, and K.J. Rodnick. 1984. Assessment of habitat quality models for cutthroat trout (*Salmo clarki clarki*) and coho salmon (*Oncorhynchus kisutch*) for Oregon's coastal streams. U.S. Fish and Wildlife Service Biological Report 85(6):57-112.
{HABITAT, QUALITY, MODELS, COHO SALMON, CUTTHROAT TROUT}

Linstone, A.A., and M. Turoff, editors. 1975. The Delphi method. Addison-Wesley, Reading, Massachusetts.
{HABITAT, MODELS, METHODS, DELPHI}

Loar, J.M., editor. 1984. Application of habitat evaluation models in southern Appalachian trout streams. Oak Ridge National Laboratory, ORNL/TM-9323, Oak Ridge.
{HABITAT, EEP, MODELS, METHODS, SALMONID}

Ludlow, J.D. 1972. Evaluation of methodology in the University of Michigan's Sea Grant Delphi inquiry. University of Michigan Sea Grant, Technical Report 22, Ann Arbor.
{HABITAT, MODELS, METHODS, DELPHI)

Marcus, M.D., W.A. Hubert, and S.H. Anderson. 1984. Habitat suitability index models: lake trout (exclusive of the Great Lakes). U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.84, Washington, D.C.
{HABITAT, HSI, MODELS, LAKE TROUT}

Mathur, D., W.H. Bason, E.J. Purdy, Jr., and C.A. Silver. 1985. A critique for the instream flow incremental methodology. Canadian Journal of Fisheries and Aquatic Sciences 42:825-831.
{HABITAT, FLOW, ISIM, MODELS, METHODS}

McClendon, D.D., and C.F. Rabeni. 1987. Physical and biological variables useful for predicting population characteristics of smallmouth bass and rock bass in an Ozark stream. North American Journal of Fisheries Management 7:46-56.
{HABITAT, MULTIPLE REGRESSION, PSD, MODELS, SMALLMOUTH BASS}

McMahon, T.E. 1982. Habitat suitability index models: creek chub. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-84/11 , Washington,

&TAT, BSI, MODELS, CREEK CHUB}

McMahon, T.E. 1983. Habitat suitability index models: coho salmon. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-84/11 , Washington, D.C.
{HABITAT, HSI, MODELS, COHO SALMON}

McMahon, T.E., G. Gebhart, O.E. Maughan, and P.C. Nelson. 1984a. Habitat suitability index models and instream flow suitability curves: warmouth. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.67, Washington, D.C.
{HABITAT, HSI, MODELS, WARMOUTH}

McMahon, T.E., G. Gebhart, O.E. Maughan, and P.C. Nelson. 1984b. Habitat suitability index models and instream flow suitability curves: spotted bass. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.67, Washington, D.C.
{HABITAT, HSI, MODELS, SPOTTED BASS}

McMahon, T.E., J.W. Terrell, and P.C. Nelson. 1984. Habitat suitability information: walleye. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.56, Washington, D.C.
[HABITAT, HSI, MODELS, WALLEYE)

Milhous, R.T., D.L. Wenger, and T. Waddle. 1981. Users guide to physical habitat simulation system. U.S. Fish and Wildlife Service, Instream Flow Information Paper 11, FWS/OBS-81/43, Ft. Collins, CO, USA.

{HABITAT, mow, ISIM, MODELS, METHODS}

Milner, N.J., R.J. Hemsworth, and B.E. Jones. 1985. Habitat evaluation as a fisheries management tool. Journal of Fish Biology 27(Supplement A) :85-108.
{HABITAT, REP, MODELS, METHODS}

Moyle, P.B., and D.M. Baltz. 1985. Microhabitat use by an assemblage of California stream fishes: developing criteria for instream flow determinations. Transactions of the American Fisheries Society 114:695-704.
{HABITAT, FLOW, ISIM, MODELS, METHODS}

Newcombe, C. 1981. A procedure to estimate changes in fish populations caused by changes in stream discharge. Transactions of the American Fisheries Society 110:382-390.
[HABITAT, FLOW, MODELS, METHODS}

Orth, D.J. 1980. Evaluation of a methodology for recommending instream flows for fishes. Doctoral dissertation. Oklahoma State University, Stillwater, OK, USA.
{HABITAT, FLOW, ISIM, MODELS, METHODS}

Orth, D.J., and O.E. Maughan. 1981. Evaluation of the "Montana method" for recomending instream flows in Oklahoma streams. Procedings of the Oklahoma Academy of Science 61:62-66.
(HABITAT, FLOW, ISIH, MODELS, METHODS}

Orth, D.J., and O.E. Maughan. 1982. Evaluation of the incremental methodology for recomending instream flow for fishes. Transactions of the American Fisheries Society 111:413-445.
{HABITAT, FLOW, ISIM, MODELS, METHODS}

Oswood, M.E., and W.E. Barber. 1982. Assessment of fish habitat in streams: goals, constraints, and a new technique. Fisheries (Bethesda) 7(3):8-11.
{HABITAT, FLOW, MODELS, METHODS}

Pajak, P., and R.J. Neves. 1987. Habitat suitability and fish production: a model evaluation for rock bass in two Virginia streams. Transactions of the American Fisheries Society 116:839-850.
{HABITAT, HSI, MODELS, ROCK BASS]

Paragamian, V.L. 1981. Some habitat characteristics that affect abundance and winter survival of smallmouth bass in Maquoketa River, Iowa. Pages 45-53 *in* L.A. Krumholz, editor. Warmwater streams symposium. American Fisheries Society, Southern Division, Bethesda, Maryland.
{HABITAT, ABUNDANCE, MORTALITY, SMALLMOUTH BASS}

Pardue, G.B. 1983. Habitat suitability index models: alewife and blueback herring. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.58, Washington, D.C.
{HABITAT, ESI, MODELS, ALEWIFE, BLUEBACK HERRING)

Prewitt, C.G., and C.A. Carlson. 1979. Evaluation of four instream flow methodologies used on the Yampa and White rivers, Colorado. U.S. Bureau of Land Management, Biological Sciences Series 2, Denver, Colorado.
{HABITAT, FLOW, ISIM, MODELS, METHODS}

Raleigh, R.F. 1978. Habitat evaluation procedures for aquatic assessments. Pages 131-157 in W.T. Mason, Jr., editor. Methods for the assessment and prediction of mineral mining impacts on aquatic communities: a review and analysis. Eastern Energy and Land Use Group, Harpers Ferry, WV, USA
[HABITAT, HEP, MODELS, METHODS}

Platts, W.S. 1980. A plea for fishery habitat classification. Fisheries (Bethesda) 5(1):2-6.
{HABITAT, METHODS}

Platts, U.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. U.S. Forest Service General Technical Report INT-138.
[HABITAT, STREAM, METHODS}

Project Evaluation Team. 1979. Habitat evaluation procedures. U.S. Fish and Wildlife Service, Division of Ecological Sciences, Fort Collins, Colorado.
[HABITAT, HEP, MODELS, METHODS}

Raleigh, R.F. 1982. Habitat suitability index models: brook trout. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.24, Washington, D.C.
{HABITAT, HSI, MODELS, BROOK TROUT}

Raleigh, R.H., T. Hickman, R.C. Solomon, and P.C. Nelson. 1984. Habitat suitability information: rainbow trout. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.60, Washington, D.C.
{HABITAT, HSI, MODELS, RAINBOW TROUT}

Raleigh, R.F., W.J. Miller, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: chinook salmon. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.122, Washington, D.C.
[HABITAT, HSI, MODELS, CHINOOK SALMON}

Raleigh, R.F., and P.C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: pink salmon. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.109, Washington, D.C.
(HABITAT, BSI, MODELS, PINK SALMON!

Raleigh, R.F., L.D. Zuckerman, and P.C. Nelson. 1986. Habitat suitability index models: brown trout. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.124, Washington, D.C.
{HABITAT, HSI, MODELS, BROWN TROUT}

Schamberger, M., A.H. Farmer, J.W. 1982. Habitat suitability index models: introduction. U.S. Fish and Wildlife Service, FWS/OBS-82/10.
(HABITAT, HSI, MODELS, METHODS}

Shirvell, C.S. 1986. Pitfalls of physical habitat simulation in the instream flow incremental methodology. Canadian Technical Report of Fisheries and Aquatic Sciences 14: 68 p.
{HABITAT, IFIM, MODELS, METHODS}

Stalkner, C.B. 1978. The IFG incremental methodology for physical instream habitat evaluation. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-78/81:126-135.
{HABITAT, IFIM, MODELS, METHODS}

Stalkner, C.B. 1979. The use of habitat structure preferenda for establishing flow regimes necessary for maintenance of fish habitat. Pages 192-199 *in* J.V. Ward and J.A. Stanford, editors. The ecology of regulated streams. Plenum Press, New York.
{HABITAT, FLOW, STRUCTURE, METHODS}

Stalkner, C.B. 1981. Low flow as a limiting factor in warmwater streams. Pages 192-199 *in* L.A. Krumholz, editor. The warmwater streams symposium. American Fisheries Society, Southern Division, Bethesda, Maryland.
[HABITAT, FLOW, WARXWATER, STREAMS}

Stalkner, C.B., and J.L. Arnette, editors. 1976. Methodologies for the determination of stream resource flow requirements: an assessment. U.S. Fish and Wildlife Service, Office of Biological Services, Western Water Allocation, Washington, D.C.
{HABITAT, FLOW, STREAM, METHODS}

Stickney, R.R., and M.L. Cuenco. 1982. Habitat suitability index models: juvenile spot. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.20, Washington, D.C.
(HABITAT, HSI, MODELS, JUVENILE SPOT}

Stier, D.J., and J.H. Crance. 1985. Habitat suitability index models and instream flow suitability curves: American shad. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.88, Washington, D.C.
IEABITAT, HSI, MODELS, AMERICAN SHAD}

Stuber, R.J. 1982. Habitat suitability index models: black bullhead. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.14, Washington, D.C.
[HABITAT, HSI, MODELS, BLACK BULLHEAD}

Stuber, R.J., G. Gebhart, and O.E. Maughan. 1982a. Habitat suitability index models: bluegill. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.8, Washington, D.C.
{HABITAT, BSI, MODELS, BLUEGILL)

Stuber, R.J., G. Gebhart, and O.E. Maughan. 1982b. Habitat suitability index models: green sunfish. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.15, Washington, D.C.
{HABITAT, HSI, MODELS, GREEN SUNFISH}

Stuber, R.J., G. Gebhart, and O.E. Maughan. 1982c. Habitat suitability index models: largemouth bass. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.16, Washington, D.C.
{HABITAT, HSI, MODELS, LARGEMOUTH BASS}

Tennant, D.L. 1976. Instream flow regimens for fish, wildlife, recreation, and related environmental resources. Pages 359-373 *in* J.F. Osborn and C.H. Allman, editors. Instream flow needs, volume 2. American Fisheries Society, Western Division, Bethesda, Maryland.
(HABITAT, FLOW, STREAM, METHODS}

Terrell, J.W., editor. 1984. Proceedings of a workshop on fish habitat suitability index models. U.S. Fish and Wildlife Service, Biological Report 85 (6).
{HABITAT, HSI, MODELS}

Terrell, J.W., T.E. McMahon, P.D. Inskip, R.F. Raleigh, and K.L. Williamson. 1982. Habitat suitability index models: Appendix A. Guidelines for riverine and lacustrine applications of fish HSI models with the habitat evaluation procedures. U.S. Fish and Wildlife Service, FWS/OBS-82/10.A.
{HABITAT, HSI, MODELS, METHODS}

Theurer, F.D., and K.A. Voos. 1982. IFG's instream water temperature model validation. Pages 513-518 *in* F. Kilpatrick and D. Matchett, editors. Procedings of the conference on water and energy technical and policy issues. American Society of Civil Engineering.
{HABITAT, INSTREAM FLOW, TEMPERATURE, MODELS}

Trial, J.G., J.G. Stanley, M. Batcheller, G. Gebhart, O.E. Maughan, and P.C. Nelson. 1982. Habitat suitability index models: blacknose dace. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.41, Washington, D.C.
(HABITAT, BSI, MODELS, BLACKNOSE DACE}

Trial, J.G., C.S. Wade, J.G. Stanley, and P.C. Nelson. 1983a. Habitat suitability index models: common shiner. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.40, Washington, D.C.
{HABITAT, BSI, MODELS, COMMON SHINER)

Trial, J.G., C.S. Wade, J.G. Stanley, and P.C. Nelson. 1983b. Habitat suitability information: fallfish. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.48, Washington, D.C.
{HABITAT, ESI, MODELS, FALLFISH}

Trihey, E.W. 1979. The IFG incremental methodology. Pages 24-44 *in* G.L. Smith, editor. Proceedings, workshop in instream flow habitat criteria and

modeling. Colorado State University, Colorado Water Resources Research Institute, Information series 40, Fort Collins.
{HABITAT, FLOW, IFIM, MODELS, METHODS}

Trihey, E.W., and D.L. Wegner. 1981. Field data collection procedures for use with the physical habitat simulation system of the Instream Flow Group. U.S. Fish and Wildlife Service, Fort Collins, Colorado.
{HABITAT, FLOW, ISIM, MODELS, METHODS}

USFWS (U.S. Fish and Wildlife Service). 1979. Assessing the impacts of development on fish and wildlife. Pages l-3 in The bulletin, habitat preservation news, volume 3, Washington, D.C.
{HABITAT, EEP, MODELS, METHODS)

USFWS (U.S. Fish and Wildlife Service). 1980a. Habitat as a basis for environmental assessment, 101 ESM. Division of Ecological Services, Washington, D.C.
{HABITAT, HEP, MODELS, METHODS)

USFWS (U.S. Fish and Wildlife Service). 1980b. Habitat evaluation procedures (HEP). Division of Ecological Services, Washington, D.C.
{HABITAT, HEP, MODELS, METHODS}

USFWS (U.S. Fish and Wildlife Service). 1981. Standards for the development of habitat suitability index models. 103 ESM. Division of Ecological Services, Washington, D.C.
{HABITAT, BSI, MODELS, METHODS}

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47:893-901.
{HABITAT, QUALITY, DENSITY}

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.
{HABITAT, FLOW, RIVER CONTINUUM, THEORY}

Waters, B.F. 1976. A methodology for evaluating the effects of different stream flows on salmonid habitat. Pages 245-256 in J.F. Osborn and C.H. Allman, editors. Instream flow needs, volume 2. Western Division, American Fisheries Society, Bethesda, MD, USA.
{HABITAT, FLOW, METHODS}

Wesche, T.A. 1973. Parametric determination of minimum stream flow for trout. University of Wyoming, Water Resources Research Institute, Water Resources Series Number 37, Laramie.
{HABITAT, FLOW, MODELS, TROUT}

Wesche, T.A. 1974. Relationships of discharge reductions to available trout habitat for recommending suitable streamflows. University of Wyoming, Water Resources Research Institute, Water Resources Series Number 53, Laramie.

{HABITAT, FLOW, MODELS, TROUT}

Wesche, T.A. 1980. The WRRI trout cover rating method. University of Wyoming, Water Resources Research Institute, Water Resources Series Number 78, Laramie.
{HABITAT, FLOW, HODELS, TROUT}

Wesche, T.A., C.M. Goertler. and W.A. Hubert. 1987. Modified habitat model for brown trout in southeastern Wyoming. North American Journal of Fisheries Management 7:232-237.
{HABITAT, MODELS, BROWN TROUT}

Williamson, K.L., and P.C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: gizzard shad. U.S. Fish and Wildlife Service, Technical Publication FWS/OBS-82/10.112 , Washington, D.C.
[HABITAT, HSI, MODELS, GIZZARD SHAD}

Winger, P.V. 1981. Physical and chemical characteristics of warmwater streams: a review. Pages 32-44 in L.A. Krumholz, editor. The warmwater streams symposium. Southern Division, American Fisheries Society, Bethesda, MD, USA
{HABITAT, WARMWATER, STREAMS}

Zuboy, J.R. 1981. A new tool for fishery managers: the Delphi technique. North American Journal of Fisheries Management 1:55-59.
{HABITAT, METHODS, SURVEY, DELPHI]

APPENDIX A-5. Selected bibliography on factors regulating fish year class strength, and compensatory mechanisms in fish populations.

Anthony, D.D., and C.R. Jorgensen. 1977. Factors in the declining contributions of walleye *(Stizostedion vitreum vitreum)* to the fishery of Lake Nipissing, Ontario, 1960-1976. Journal of the Fisheries Research Board of Canada 34:1703-1709.
{YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, WALLEYE]

Baccante, D., and D.M. Reid. 1988. Fecundity changes in two exploited walleye populations. North American Journal of Fisheries Management 8:199-209.
{COMPENSATION, FECUNDITY, WALLEYE}

Bagenal, T.B. 1969. The relationship between food supply and fecundity in brown trout, *Salmo trutta* Linnaeus. Journal of Fish Biology.
{COMPENSATION, FECUNDITY, SALMONIDS}

Bagenal, T.B. 1973. Fish fecundity and its relations with stock and recruitment. Rapports et Proces-Verbaux des Reunions. Conseil International pour l'Exploration de la Mer 164:186-198.
{COMPENSATION, FECUNDITY, STOCK, RECRUITMENT}

Bosclair, D., and W.C. Leggett. 1989. Among-population variability in fish growth: III. Influence of fish community. Canadian Journal of Fisheries and Aquatic Sciences 46: 1539-1550.
{COMPENSATION, SYNECOLOGY, GROWTH]

Brege, D.A. 1981. Growth characteristics of young-of-the-year walleye, *Stizostedion vitreum vitreum,* in John Day Reservoir on the Columbia River, 1979. Fisheries Bulletin 79:567-569.
{YEAR-CLASS, GROWTH, WALLEYE, COLUMBIA RIVER}

Busch, W.-D.N., R.L. Scholl, and W.L. Hartman. 1975. Environmental factors affecting the strength of walleye *(Stizostedion vitreum vitreum)* year-classes in western Lake Erie, 1960-70. Journal of the Fisheries Research Board of Canada 32:1733-1743.
[YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, WALLEYE}

Carlander, K.D. 1943. The walleyes *Stizostedioa vitreum* (Mitchell), of Lake of the Woods, with special reference to the commercial fisheries. Ph.D. dissertation. University of Minnesota, St. Paul, Minnesota. 202 pp.
[COMPENSATION, FRESHWATER, COMMERCIAL, FISHERIES, WALLEYE}

Carlander, K.D. 1945. Growth, length-weight, relationship and population fluctuations of the yellow pike-perch, *Stizostedion vitreum vitreum* (Mitchill) with reference to the commercial fisheries, Lake of the Woods, Minnesota. Transactions of the American Fisheries Society 73:90-103.
{COMPENSATION, FRESHWATER, COMMERCIAL, FISHERIES, WALLEYE}

Carlander, K.D. 1948a. Some changes in the fish population of Lake of the Woods, Minnesota, 1910 to 1945. Copeia 1948:271-274.
[COMPENSATION, FRESHWATER, COMMERCIAL, FISHERIES, WALLEYE]

Carlander, K.D. 1948b. Growth of the yellow pike-perch, *Stizostedion vitreum vitreum* (Mitchill), in some Iowa Lakes, with a summary of growth rates reported in other areas. Iowa State College Journal of Science 22:227-237.
{COMPENSATION, FRESHWATER, COMMERCIAL, FISHERIES, WALLEYE}

Carlander, K.D. 1949. Some trends of the commercial fisheries of Lake of the Woods, Minnesota. Transactions of the American Fisheries Society 77:13-25.
{COMPENSATION, FRESHWATER, COMMERCIAL, FISHERIES, WALLEYE}

Carlander, K.D., and P.M. Payne. 1977. Year-class abundance, population, and production of walleye (*Stizostedion vitreum vitreum*) in Clear Lake, Iowa, 1948-74, with reference to stocking rates. Journal of the Fisheries Research Board of Canada 34:1792-1799.
WEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, WALLEYE}

Cheng, C.W. 1987. Compensatory mechanisms in fish populations: literature reviews. Volume 3: a critical review of mathematical models for fish compensation mechanisms. Final Report EA-5200, Volume 3, Research Project 1633-6. Prepared for Electric Power Research Institute, Palo Alto, California.
{COMPENSATION, MODELING, LITERATURE REVIEW}

Chevalier, J.R. 1973. Canabilism as a factor in first year survival of walleye in Oneida Lake. Transactions of the American Fisheries Society 102:739-744.
{YEAR-CLASS, ABUNDANCE, PREDATION, ENVIRONMENTAL, WALLEYE}

Chevalier, J.R. 1977. Changes in walleye (*Stizostedion vitreum vitreum*) population in Rainy Lake and factors in abundance, 1924-75. Journal of Fisheries Research Board of Canada 34:1696-1702.
{YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, COMPENSATION, WALLEYE}

Christie, W.J., G.R. Spangler, K.H. Loftus, W.L. Hartman, P.J. Colby, M.A. Ross, and D.R. Talhelm. 1987. A perspective on Great Lakes fish community rehabilitation. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):486-499.
{SYNECOLOGY, GREAT LAKES, WALLEYE}

Cohen, Y., J.N. Stone, T.L. Vincent. 1987. Vulnerability, stability, and coherence of the fish community in Lake Superior. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):404-410.
{SYNECOLOGY,GREATLAKES,WALLEYE)

Colby, P.J., R.E. McNicol, and R.A. Ryder. 1979. Synopsis of biological data on the walleye, *Stizostedion vitreum vitreum* (Mitchill 1818). FAO Fisheries Synopsis 119, Rome, Italy. 140 pp.
{SYNECOLOGY, COMPENSATION, BIBLIOGRAPHY, WALLEYE]

Colby, P.J., and S.J. Nepszy. 1981. Variation among stocks of walleye (*Stizostedion vitreum vitreum):* management implications. Canadian Journal of Fisheries and Aquatic Sciences 38:1814-1831.
{POPULATIONS, MANAGEMENT, COMPENSATION, WALLEYE}

Colby, P.J., P.A. Ryan, D.H. Schupp, and S.L. Serns. 1987. Interactions in north-temperate lake fish communities. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):104-128.
ISYNECOLOGY, GREAT LAKES, WALLEYE}

Cooper, J.C., and T.T. Polgar. 1981. Recognition of year-class dominance in striped bass management. Transactions of the American Fisheries Society 110:180-187.
{YEAR-CLASS, ABUNDANCE, MANAGEMENT, ENVIRONMENTAL, STRIPED BASS}

Craig, J.F., and K. Smiley. 1986. Walleye, *Stizostedion vitreum vitreum* and northern pike *Esox lucius*, populations in three Alberta lakes. Journal of Fish Biology 29:67-85.
{SYNECOLOGY, FRESHWATER, WALLEYE, NORTHERN PIKE}

Crecco, V., T. Savoy, and L. Gunn. 1983. Daily mortality rates of larval and juvenile American shad (*Alosa sapidissima*) in the Connecticut River with changes in year-class strength. Canadian Journal of Fisheries and Aquatic Sciences 40:1719-1728.
(YEAR-CLASS, ABUNDANCE, MORTALITY, AMERICAN SHAD}

Dablberg, M.D. 1979. A review of survival rates of fish eggs and larvae in relation to impact assessments. Marine Fisheries Review, United States Department of the Commerce, March, 1979. 40 p.
[YEAR-CLASS, ABUNDANCE, MORTALITY, EARLY LIFE]

Dey, W.P. 1981. Mortlaity and growth of young-of-the-year striped bass on the Hudson River Estuary. Transaction of the American Fisheries Society. 110:151-157.
{YEAR-CLASS, ABUNDANCE, GROWTB, MORTALITY, EARLY LIFE}

Diamond, J. and H.J. Pribble. 1978. A review of factors affecting seaward migration and survival of juvenile salmon in the Columbia River and ocean.
{REVIEW, FACTORS, MIGRATION, SURVIVAL)

Diana, J.S. 1983. Growth, maturation, and production of northern pike in three Michigan lakes. Transactions of the American Fisheries Society 112:38-46.
{COMPENSATION, GROWTH, MATURITY, ESCOSIDS}

Eck, G.W., and L. Wells. 1987. Recent changes in Lake Michigan's fish community and their probable causes, with emphasis on the role of the alewife (*Alosa pseudoharengus*). Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):53-60.
ISYNECOLOGY, PREDATION, GREAT LAKES, ALEWIFE]

Evans, D.O., B.A. Henderson, N.J. Bax, T.R. Marshall, R.T. Oglesby, and W.J. Christie. 1987. Concepts and methods of community ecology applied to freshwater fisheries management. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):448-470.
{SYNECOLOGY, MANAGEMENT, FRESHWATER, FISHERIES}

Evans, D.O., and D.H. Loftus. 1987. Colonization of inland lakes in the Great Lakes region by rainbow smelt, *Osmerus mordax:* their freshwater niche and effects of indigenous fishes. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):249-266.
{SYNECOLOGY, GREAT LAKES, WALLEYE]

Forney, J.L. 1961. Year-class distribution of walleyes collected in five types of gear. Transactions of the American Fisheries Society 90:308-311.
[YEAR-CLASS, ABUNDANCE, METHODS, WALLEYE]

Forney, J.L. 1965. Factors affecting growth and maturity in a walleye population. New York Fish and Game Journal 12:217-232.
{COMPENSATION, GROWTH, MATURITY, WALLEYE)

Forney, J.L. 1966. Factors affecting first year growth of walleyes in Oneida Lake, New York. New York Fish and Game Journal 13:146-167.
(YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, WALLEYE}

Forney, J.L. 1971. Development of dominant year classes in a yellow perch population. Transactions of the American Fisheries Society 100:739-749.
[YEAR-CLASS, ABUNDANCE, PERCIDS}

Forney, J.L. 1974. Interactions between yellow perch abundance, walleye predation and survival of alternate prey in Oneida Lake, New York. Transactions of the American Fisheries Society 103:15-24.
[SYNECOLOGY, PREDATION, FRESHWATER, WALLEYE]

Forney, J.L. 1975. Contribution of stocked fry to walleye fry populations in New York lakes. Progressive Fish-Culturist 37:20-24.
{YEAR-CLASS, ABUNDANCE, WALLEYE}

Forney, J.L. 1976. Year-class formation in the walleye *(Stizostedion vitreum* vitreum) population of Oneida Lake, New York, 1966-73. Journal of the Fisheries Research Board of Canada 33:783-792.
{YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, WALLEYE}

Forney, J.L. 1977a. Reconstruction of yellow perch (*Perca flavescens*) cohorts from examination of walleye *(Stizostedion vitreum vitreum*) stomachs. Journal of the Fisheries Research Board of Canada 34:925-932.
[YEAR-CLASS, ABUNDANCE, METHODS, DIET, PERCIDS, WALLEYE]

Forney, J.L. 1977b. Evidence of inter- and intra-specific competition as factors regulating walleye *(Stizostedion vitreum vitreum)* biomass in Oneida Lake, New York. Journal of the Fisheries Research Board of Canada 34:1812-1820.
[SYNECOLOGY, YEAR-CLASS, ABUNDANCE, COHPETITION, WALLEYE]

Forney, J.L. 1980. Evolution of a management strategy for the walleye in Oneida Lake, New York. New York Fish and Game Journal 27:105-141.
{MANAGEMENT, SYNECOLOGY, WALLEYE}

Franklin, D.R., and L.L. Smith. 1963. Early life history of the northern pike, *Esox lucius* L., with special reference to the factors influencing the numerical strength of year classes. Transactions of the American Fisheries Society 92:91-110.
{YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, NORTEERN PIKE}

Fredin, R.A. 1954. Causes of fluctuations in abundance of Connecticut River shad. Fisheries Bulletin 54:247-259.
{YEAR-CLASS, ABUNDANCE, AMERICAN SHAD}

Gabelhouse, D.W., Jr. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273-285.
WEAR-CLASS, ABUNDANCE, METHODS, SIZE COMPOSITION}

Grimm, M.P. 1983. Regulation of biomasses of small (less than 41 cm) northern pike (*Esox lucius*), with special reference to the contribution of individuals stocked as fingerlings (4-6 cm). Fisheries Management 14:115-134.
{COMPENSATION, MANAGEMENT, PREDATION, NORTHERN PIKE}

Grinstead, B.G. 1975. Response of bass to removal of competing species by commercial fishing. Pages 475-479 *in* H.E. Clepper, editor. Black bass biology and management. Sport Fishing Institute, Washington, D.C.
{COMPENSATION, MANAGEMENT, COMPETITION, CENTRARCHIDS}

Gulland, J.A. 1965. Survival of the youngest stages of fish, and its relation to year-class strength. Special Publication of the International Commission for the Northwest Atlantic Fisheries (ICNAF) 6:363-371.
[YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL}

Hatch, R.W., S.J. Nepszy, K.M. Muth, and C.T. Baker. 1987. Dynamics of the recovery of the western Lake Erie walleye (*Stizostedion vitreum vitreum*) stock. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):15-22.
[YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, WALLEYE]

Hauber, A.B. 1983. Two methods for evaluating fingerling walleye stocking success and natural year-class densities in Seven Island Lake, Wisconsin, 1977-1981. North American Journal of Fisheries Management 3:152-155.
[YEAR-CLASS, ABUNDANCE, HETHODS, WALLEYE]

Healey, M.C. 1978a. Fecundity changes in exploited populations of lake whitefish (*Coregonus clupeaformis*) and lake trout (*Salvelinus namaycush*). Journal of the Fisheries Research Board of Canada 42:307-327.
{COMPENSATION, FECUNDITY, LAKE TROUT, LAKE WHITEFISH}

Healey, M.C. 1978b. The dynamics of exploited lake trout populations and implications for management. Journal of Wildlife Management 42:307-327.
{COMPENSATION, MANAGEMENT, LAKE TROUT}

Iiealey, M.C., and W.R. Heard. 1984. Inter- and intra-population variation in the fecundity of the chinook salmon (*Oncorhynchus tshawytscha*) and its relevance to life history theory. Canadian Journal of Fisheries and Aquatic Sciences 41:476-483.
{COMPENSATION, FECUNDITY, CHINOOK SALMON}

Henderson, B.A. and F.E.J. Fry. 1987. Interspecific relations among fish species in South Bay, Lake Huron, 1949-84. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):10-14.
ISYNECOLOGY, GREAT LAKES, WALLEYE)

Hesse, L.W., C.R. Wallace, and L. Lehman. 1978. Fishes of the channelized Missouri. Age-growth, length-frequency, length-weight, coefficient of condition, catch curves, and mortality of 25 species of channelized Missouri River fishes. Nebraska Game and Parks Commission, Technical Series No. 4: 61 pp.
{SYNECOLOGY, MORTALITY, AGE & GROWTH, SIZE COMPOSITION}

Hile, R. 1937. The increase in abundance of the yellow pike perch (*Stizostedion vitreum*) (Mitchill) in Lake Huron and Michigan, in relation to the artificial propagation of the species. Transactions of the American Fisheries Society 66:143-159.
{YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, PERCIDS}

Hile, R. 1954. Fluctuations in growth and year class strength of the walleyes in Saginaw Bay. U.S. Fish and Wildlife Service, Fishery Bulletin 91:5-59.
{YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, WALLEYE]

Rile, R., and B.J. Buetter. 1959. Fluctuations in the commercial fisheries of Saginaw Bay, 1885-1956. U.S. Fish and Wildlife Service, Research report 51:38.
ISYNECOLOGY, COMPENSATION, WALLEYE)

Hunter, J.R. 1976. Report on a colloquium on larval fish mortality studies and their relation to fishery research, Jan. 1975. NOAA (National Oceanographic and Atmospheric Administration) Technical Report, National Marine Fisheries Service Circular-395: 5 p.
{LARVAL FISH, NORTALITY, REVIEW]

Jenkins, R.M., and D.I. Morais. 1976. Prey-predator relations in the predator stocking-evaluation- reservoirs. Annual Proceedings Conference Southeastern Association of Fish and wildlife Agencies 30:141-157.
[SYNECOLOGY, MANAGEMENT, PREDATION]

Jensen, A.L. 1971. Response of brook trout populations to a fishery. Journal of the Fisheries Research Board of Canada 28:458-460.

{YEAR-CLASS,ABUNDANCE,FISHERY,SALMONIDS}

Jester, D.B., C. Sanchez, D.E. Jennings, and T.M. Moody. 1969. A study of game fish reproduction and rough fish problems in Elephant Butte Lake. New Mexico Department of Game and Fish. Federal Aid Fish and Wildlife Restoration Project F-22-R-9, Job No. F-l: 73 pp.
{COMPENSATION,REPRODUCTION,RESERVOIRS,WALLEYE,NON-GAME}

Johnson, F.H. 1969. Environmental and species associations of the walleye in Lake Winnibigoshish and connected waters, including observations on food habits and predator-prey relationships. Minnesota Department of Conservation, Fisheries Investigations No. 5:5-36.
{SYNECOLOGY, PREDATION, WALLEYE}

Johnson, F.H. 1971. Survival of stocked walleye fingerlings in northern Minnesota Lakes as estimated from the age-composition of experimental gill net catches. Minnesota Department of Natural Resources, Investigation Report No. 314: 12 pp.
[YEAR-CLASS, ABUNDANCE, METHODS, WALLEYE]

Johnson, F.H. 1977. Responses of walleye (*Stizostedion vitreum vitreum)* and yellow perch (*Perca flavescens*) populations to removal of white sucker (*Catostomus commersoni*) from a Minnesota Lake, 1966. Journal of the Fisheries Research Board of Canada 34:1633-1642.
{SYNECOLOGY, COEPRNSATION, PREDATION, COMPETITION, WALLEYE, PERCIDS, CATOSTOOHIDS]

Johnson, F.H., and J.G. Hale. 1977. Interrelationships between of walleye (*Stizostedion vitreum vitreum)* and smallmouth bass (*Salmoides dolomieui*) in four northeastern Minnesota lakes, 1948-69. Journal of the Fisheries Research Board of Canada 34:1626-1632.
{SYNECOLOGY, YEAR CLASS, COMPENSATION, PREDATION, CORPETITION, WALLEYE, SMALLMOUTH BASS]

Jude, D.J., P.J. Mansfield, P.J. Schneeberger, and J.A. Wojcik. 1987. Compensatory mechanisms in fish populations: literature reviews. Volume 2: compensation in fish populations subject to catostrophic impact. Final Report EA-5200, Volume 2, Research Project 1633-6. Prepared for Electric Power Research Institute, Palo Alto, California.
{COMPENSATION, IMPACTS, LITERATURE REVIEW]

Kallemeyn, L. 1987. Correlations of regulated lake levels and climatic factors with abundance of young-of-the-year walleye and yellow perch in four lakes in Voyageurs National Park. North American Journal of Fisheries Management 7:513-521.
{YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, PERCIDS, WALLEYE}

Kelso, J.R.M., and F.J. Ward. 1977. Unexploited percid populations of West Blue Lake, Manitoba, and their interactions. Journal of the Fisheries Research Board of Canada 34:1655-1669.
{SYNECOLOGY, FRESHWATER, PERCID, WALLEYE}

Kempinger, J.J., and R.F. Carline. 1977. Dynamics of the walleye (*Stizostedion vitreum vitreum*) population in Escanaba Lake, Wisconsin, 1955-72. Journal of the Fisheries Research Board of Canada 34:1800-1811.
[POPULATION DYNAMICS, TREND, WALLEYE]

Ketchen, K.S. 1950. Stratified subsampling for determining age distributions. Transactions of the American Fisheries Society 79:205-212.
[YEAR-CLASS, ABUNDANCE, METHODS]

Kinman, B.T. 1982. An evaluation of walleye introductions at Nolin River Lake, Kentucky. Kentucky Department of Fish and Wildlife Resources, Special Report No. 4:21 pp.
[MANAGEMENT, FRESHWATER, WALLEYE]

Kipling, C., and W.E.F. Frost. 1970. A study of the mortality, population numbers, year class strengths, production and food consumption of pike, *Esox lucius* L., in Windermere from 1944 to 1962. Journal of Animal Ecology 39:115-157.
[YEAR-CLASS, ABUNDANCE, CONSUMPTION, ENVIRONMENTAL, NORTHERN PIKE]

Koonce, J.F., T.B. Bagenal, R.F. Carline, K.E. Hokanson, and M. Nagiec. 1977. Factors influencing year-class strength of percids: a summary and a model of temperature effects. Journal of the Fisheries research Board of Canada 34:1900-1909.
[YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, PERCIDS]

Kramer, R.H., and Smith. 1960. First year growth of the largemouth bass, *Micropterus salmoides* (Lacepede), and some related ecological factors. Transactions of the American Fisheries Society 89:222-223.
[YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, CENTRARCHIDS]

Laarman, P.W., and J.C. Schneider. 1986. Walleye stocking experiments and fish population studies at Manistee Lake, 1972-84. Michigan Department of Natural Resources, Fisheries Research Report No. 1938: 43 pp.
[MANAGEMENT, FRESHWATER, WALLEYE]

LaBar, G.W., and S. Parren. 1983. A comprehensive examination of data and data analysis on walleye from Lake Champlain: 1903 to the present. Vermont Fish and Game Department. 57 pp.
[SYNRCOLOGY, GREAT LAKES, WALLEYE]

Lett, P.F., and A.C. Koehler. 1976. Recruitment: a problem of multispecies interaction and environmental perturbations, with special reference to Gulf of St Lawrence Atlantic Herring (*Clupea harengus harengus*). Journal of the Fisheries Research Board of Canada 33:1353-1371.
[YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, MARINE]

Li, S., and J.A. Mathias. 1982. Causes of high mortality among cultured larval walleyes. Transactions of the American Fisheries Society 111:710-721.
[YEAR-CLASS, MORTALITY, ABUNDANCE, FOOD AVAILABILITY]

Lloyd, D.S., J.P. Koenings, and J.D. LaPerriere. 1987. Effects of turbidity on fresh waters of Alaska. North American Journal of Fisheries Management 7:18-33.
[YEAR-CLASS, TURBIDITY, MORTALITY, ABUNDANCE, FOOD AVAILABILITY]

Machniak, K. 1975. The effects of hydroelectric development on the biology of northern fishes (reproduction and population dynamics). III. Yellow walleye (*Stizostedion vitreum* vitreum (Mitchill). A literature review and bibliography. Canadian Fisheries and Marine Service Research and Development Technical Report 529: 68 pp.
[YEAR-CLASS, ABUNDANCE, REPRODUCTION, ENVIRONMENTAL, WALLEYE, BIBLIOGRAPHY]

MacLean, J.A., B.J. Shuter, H.A. Regier, and J. C. MacLeod. 1981. Temperature and year class strength of smallmouth bass. Rapports et Proces-Verbaux des Reunions, Conseil International pour l'Exploration de la Mer 178:30-40.
HEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, SMALLMOUTH BASS)

Marshall, T.R., and P.A. Ryan. 1987. Abundance patterns and community attributes of fishes relative to environmental gradients. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):198-215.
{SYNECOLOGY, ENVIRONMENTAL, FRESHWATER, WALLEYE}

Marr, J.C. 1956. The "critical period" in the early life history of marine fishes. J. Cons. Int. Explor. Her 21:160-170.
[YEAR-CLASS, ABUNDANCE, HORTALITY, CRITICAL PERIOD, MARINE]

Maule, A.G., and H.F. Horton. 1985. Probable causes of the rapid growth and high fecundity of walleye, *Stizostedion vitreum vitreum in* the mid-Columbia River. U.S. National Marine Fisheries Service Fisheries Bulletin 83:701-706.
{COMPENSATION, GROWTH, FECUNDITY, COLUMBIA RIVER, WALLEYE}

May, R.C. 1974. Larval mortality in marine fishes and critical period concept. Pages 3-19 in J.H.S. Blaxter, editor. The early life history of marine fish. Springer Verlag. Iieidenberg.
{YEAR-CLASS, ABUNDANCE, HORTALITY, CRITICAL PERIOD, MARINE]

Miranda, L.E. and R.J. Muncy. 1987. Recruitment of young-of-year largemouth bass in relation to sie structure of parental stock. North American Journal of Fisheries Management 7:131-137.
{YEAR-CLASS, STOCK SIZE, RECRUITMENT)

Moenig, J.T. 1975. Dynamics of an experimentally exploited walleye population in Dexter Lake, Ontario. Master's thesis. University of Toronto, Toronto.
{POPULATION DYNAMICS, MANAGEMENT, WALLEYE]

Mullan, J.W., M.B. Dell, S.G. Hays, and J.A. McGee. 1986. Some factors affecting fish production in the mid-Columbia River, 1934-1983. U.F. Fish and Wildlife Report No. FRI/FAO-86-15:1-69.

{FISH PRODUCTION, POPULATION DYNAHICS, MANAGEMENT}

Muth, K.M., and D.R. Wolfert. 1986. Changes in growth and maturity of walleyes associated with stock rehabilitation in western Lake Erie, 1964-1983. North American Journal of Fisheries Management 6:168-175.
{COMPENSATION, MANAGEMENT, GROWTH, MATURITY, TREND, GREAT LARES, WALLEYE}

Nelson, W.R. 1978. Implications of water management in Lake Oahe for the spawning success of coolwater fishes. Pages 154-158 *in* R.L. Kendall, editor. Selected coolwater fishes of North America. American Fisheries Society, Special Publication Number 11.
{YEAR-CLASS, ABUNDANCE, REPRODUCTION, WATER LEVEL, PERCIDS, WALLEYE}

Nelson, W.R., M.C. Ingham, and W.E. Schaaf. 1977. Larval transport and year-class strength of Atlantic menhadden, *Brevoortia tyrannus.* Fisheries Bulletin 75:23-41.
{YEAR-CLASS, ABUNDANCE, MARINE, CURRENTS}

Nelson, W.R., and C.H. Walberg. 1977. Population dynamics of yellow perch (*Perca flavescens*), sauger *(Stizostedion canadense)* , and walleye (*S. vitreum vitreum)* in four main stem Missouri River reservoirs. Journal of the Fisheries Research Board of Canada 34:1748-1763.
{POPULATION DYNAMICS, SYNECOLOGY, PERCIDS, WALLEYE}

Nepszy, S.J. 1977. Changes in percid populations and species interactions in Lake Erie. Journal of the Fisheries Research Board of Canada 34:1861-1868.
[SYNECOLOGY, GREAT LAKES, PERCIDS, WALLEYE]

Nepszy, S.J. 1985. Walleye *(Stizostedion vitreum)* in western Lake Erie: responses to change in predator and prey. Great Lakes Fisheries Commission, Special Publication 85-3:57-76.
[SYNECOLOGY, PREDATION, GREAT LARES, WALLEYE]

Nielsen, L.A. 1980. Effect of walleye *(Stizostedion vitreum vitreum)* predation on juvenile mortality and recruitment of yellow perch *(Perca flavescens)* in Oneida Lake, New York. Canadian Journal of Fisheries and Aquatic Sciences 37:11-19.
{YEAR-CLASS, ABUNDANCE, PREDATION, PERCIDS, WALLEYE]

Nunan, C.P. 1982. Initial effects of the exploitation of walleye *(Stizostedion vitreum vitreum* (Mitchill)) on the Boreal percid community of Henderson Lake, northwestern Ontario. Master's thesis. Lakehead University, Thunder Bay, Canada.
{COMPENSATION, EXPLOITATION, SYNECOLOGY, WALLEYE]

Oliver, J.D., G.F. Holeton, and K.E. Chua. 1979. Overwinter mortality of fingerling smallmouth bass in relation to their sire, percent storage materials and environment temperature. Transactions of the American Fisheries Society 108:130-136.
[YEAR-CLASS, MORTALITY, CONDITION, ENVIRONMENTAL, SMALLMOUTH BASS]

Olynyk, J.P.R. 1980. Lake Winnipeg walleye fecundity. Manitoba Department of Natural Resources, Manuscript Report 82-27, Winnipeg, Canada.
{COMPENSATION, FECUNDITY, WALLEYE}

Parsons, J.W. 1967. Contribution of year-classes of blue pike to the commercial fishery of Lake Erie, 1943-1959. Journal of the Fisheries Research Board of Canada 24:1035-1066.
{YEAR-CLASS, ABUNDANCE, FISHERY, PERCIDS}

Payne, P.M. 1975. Year class abundance of walleyes in Clear Lake, Iowa (1958-1974) with particular reference to fry stocking. Master's thesis, Iowa State University, Ames, Iowa. 44 pp.
[YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, WALLEYE}

Payne, P.M. 1978. Methods in determining annual production in walleye, 1948-1974 in Clear Lake, Iowa. Iowa Cooperative Fishery Research Unit, Iowa State University, Amea Project No. 2076: 69 pp.
[YEAR-CLASS, ABUNDANCE, METHODS, WALLEYE]

Pycha, R.L. 1961. Recent changes in the walleye (*Stizostedion* vitreum) fishery of northern Green Bay and history of the 1943 year class. Transactions of the American Fisheries Society 90:475-488.
{YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, WALLEYE]

Richie, B.J. 1984. Comparison of the yellow perch, *Perca flavescens* (Mitchill), populations in Henderson Lake and Savanne Lake, Ontario. Master's thesis. Lakehead University, Thunder Bay, Canada.
{COMPENSATION, FECUNDITY, ENVIRONMENTAL, PERCIDS}

Richie, B.J., and P.J. Colby. 1988. Even-odd differences in walleye year-class strength related to mayfly production. North American Journal of Fisheries Management 8:210-215.
[YEAR-CLASS, ABUNDANCE, FOOD, ENVIRONMENTAL, WALLEYE]

Reid, D.M. 1985. Effects of an episodic removal scheme on a walleye *Stizostedion vitreum vitreum* population. Master's thesis. Lakehead University, Thunder Bay, Canada.
[COMPENSATION, EXPLOITATION, WALLEYE]

Reid, D.M., and W.T. Marmot. 1985. Evaluation of pulse fishing for the walleye, *Stizostedion vitreum vitreum,* in Henderson Lake, Ontario. Journal of Fish Biology 27:235-251.
{POPULATION DYNAMICS, MANAGEMENT, WALLEYE]

Saila, S.B., X. Chen, K. Erzini, and B. Martin. 1987. Compensatory mechanisms in fish populations: literature reviews. Volume 1: critical evaluation of case histories of fish populations experiencing chronic exploitation or impact. Final Report EA-5200, Volume 1, Research Project 1633-6. Prepared for Electric Power Research Institute, Palo Alto, California.
{COMPENSATION, EXPLOITATION, LITERATURE REVIEW}

Schaaf, W.E., and G.R. Huntsman. 1972. Effects of fishing on the Atlantic Menhadden stock: 1955-1969. Transactions of the American Fisheries Society 101:290-297.
{YEAR-CLASS, ABUNDANCE, FISHERY, MARINE}

Schupp, D.H., and V. Macins. 1977. Trends in percid yields from Lake of the Woods, 1888-1973. Journal of the Fisheries Research Board of Canada 34:1784-1791.
[YEAR-CLASS, ABUNDANCE, FISEERY, PERCIDS}

Scott, D.P. 1962. Effects of food availability on fecundity of rainbow trout *Salmo gairdneri.* Journal of the Fisheries research Board of Canada 19:715-731.
{COMPENSATION, FOOD, NUTRITION, FECUNDITY, SALMONIDS}

Serns, S.L. 1982. Walleye fecundity, potential egg deposition, and survival from egg to fall young-of- year in Escanaba Lake, Wisconsin, 1979-1981. North American Journal of Fisheries Management 2:388-394.
{COMPENSATION, MORTALITY, FECUNDITY, WALLEYE]

Serns, S.L. 1987. Relationship between the size of several walleye year classes and percent harvested over the life of each cohort in Escanaba Lake, Wisconsin. North American Journal of Fisheries Management 7:305-306.
[YEAR-CLASS, ABUNDANCE, EXPLOITATION, FISHERY, WALLEYE}

Shuter, B.J., J.A. MacLean, H.A. Regier, and F.E.J. Fry. 1980. Stochastic simulation of temperature effects on first year survival of smallmouth bass. Transactions of the American Fisheries Society 109:1-34.
[YEAR-CLASS, ABUNDANCE, TEMPERATURE, SMALLMOUTH BASS}

Smith, L.L., Jr. 1977. Walleye (*Stizostedion vitreum vitreum*) and yellow perch (*Perca flavescens*) populations and fisheries of the Red Lakes, Minnesota, 1930-1975. Journal of the Fisheries Research Board of Canada 34:1774-1783.
{POPULATION DYNAMICS, SYNECOLOGY, COMPENSATION, PREDATION, FISHERIES, PERCIDS, WALLEYE}

Smith, S.H. 1968. Species succession and fishery exploitation in the Great Lakes. Journal of the Fisheries Research Board of Canada 25:667-693.
{SYNECOLOGY, FISHERIES, GREAT LAKES, WALLEYE]

Smith, S.H. 1970. Species interaction of the alewife in the Great Lakes. Transactions of the American Fisheries Society 99:754-765.
{SYNECOLOGY, GREAT LAKES, ALEWIFE, WALLEYE}

Smith, S.H. 1972. Factors of ecological succession in oligotrophic fish communities of Laurentian Great Lakes. Journal of the Fisheries Research Board of Canada 29:717-730.
{SYNECOLOGY, MECHANISMS, GREAT LAKES, WALLEYE}

Spangler, G.R., N.R. Payne, J.E. Thorpe, J.M. Byrne, H.A. Regier, and W.J. Christie. 1977. Responses of percids to exploitation. Journal of the Fisheries Research Board of Canada 34:1983-1988.
{COMPENSATION, EXPLOITATION, FISHERIES, PERCIDS, WALLEYE}

Stevens, D.E. 1977. Striped bass (*Morone saxatilis*) year class strength in relation to river flow in the Sacramento-San Joaquin estuary, California. Transactions of the American Fisheries Society 106:34-42.
[YEAR-CLASS, ABUNDANCE, FLOW, STRIPED BASS}

Stevens, D.E. and L.W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin River system. North American Journal of Fisheries Management 3:425-437.
{YEAR-CLASS, RIVER FLOW, ABUNDANCE, MORTALITY}

Sutcliffe, W.H., Jr. 1973. Correlations between seasonal river discharge and local landings of American lobster (*Homarus* americanus) and Atlantic halibut (*Hippoglossus*) in the Gulf of Saint Lawrence. Journal of the Fisheries Research Board of Canada 30:856-859.
[YEAR-CLASS, ABUNDANCE, FLOW, MARINE, FISHERIES]

Svardson, G. 1949. Natural selection and egg number in fish. Institute of Freshwater Research Drottningholm Report 29:115-122.
{COMPENSATION, MORTALITY, FECUNDITY]

Taylor, W.W., M.A. Smale, M.H. Freeburg. 1987. Biotic and abiotic determinants of lake whitefish (*Corregonus clupeaformis*) recruitment in northeastern Lake Michigan. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):313-323.
[YEAR-CLASS, ABUNDANCE, ENVIRONMENTAL, LAKE WHITEFISH)

Timmons, T.J., W.L. Shelton, and W.D. Davies. 1981. Early growth and mortality of largemouth bass in West Point Reservoir, Alabama-Georgia. Transactions of the American Fisheries Society 110:489-494.
[YEAR-CLASS, ABUNDANCE, GROWTH, CENTRARCHIDS}

Tyler, A.V., and R.S. Dunn. 1976. Ration, growth, and measures of somatic and organ condition in relation to meal frequency in winter flounders, *Pseudopleuronectes americanus,* with hypotheses regarding population homeostasis. Journal of the Fisheries Research Board of Canada 26:1877-1888.
{COMPENSATION,CONSUMPTION,BIOENERGETICS, MARINE]

Weithmann, A.S., J.B. Reynolds, and D.E. Simpson. 1979. Assessment of structure of largemouth bass stocks by sequential sampling. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 33:415-424.
{YEAR-CLASS, ABUNDANCE, METHODS, SIZE COMPOSITION, LARGEMOUTH BASS}

Werner, E. 1984. The mechanisms of species interactions and community organization in fish. Pages xxx-xxx *in* D.R. Strong, A. Simberloff, L.G.

Abele, and A.B. Thistle, editors. Ecological communities: conceptual issues and the evidence. Prinston University Press, Princeton, NJ.
{SYNECOLOGY, MECHANISMS}

Wicker, A.M., and W.E. Johnson. 1987. Relationships among fat content, condition factor, and first-year survival of Florida largemouth bass. Transactions of the American Fisheries Society 116:264-271.
{YEAR-CLASS, ABUNDANCE, NUTRITION, CONDITION, ENVIRONMENTAL, LARGEMOUTE BASS}

Willis, D.W., and J.L. Stephen. 1987. Relationships between storage ratio and population density, natural recruitment, and stocking success of walleye in Kansas reservoirs. North American Journal of Fisheries Management 7:279-282.
{YEAR-CLASS, ABUNDANCE, STORAGE RATIO, ENVIRONMENTAL, RESERVOIRS, WALLEYE}

Wolfert, D.R. 1969. Maturity and fecundity of walleyes from the eastern and western basins of Lake Erie. Journal of the Fisheries Research Board of Canada 26:1877-1888.
{COMPENSATION, MATURITY, FECUNDITY, GREAT LAKES, WALLEYE]

Woodhead, A.D. 1960. Nutrition and reproductive capacity in fish. Proceedings of the Nutrition Society 19:23-28.
{COMPENSATION, NUTRITION, REPRODUCTION, FECUNDITY}

Wooton, R.J. 1979. Energy costs of egg production and environmental determinants of fecundity in teleost fishes. Symposia of the Zoological Society of London 44:133-159.
{COMPENSATION, ENERGETICS, FECUNDITY]

APPENDIX A-6. Temperature dependent maximum daily consumption of juvenile salmonids by northern squawfish (***Ptychocheilus oregonensis***) from the Columbia River -- by Steven Vigg and Craig C. Burley. This manuscript is targeted for publication in the Canadian Journal of Fisheries and Aquatic Sciences.

# Temperature Dependent Maximum Daily Consumption of Juvenile Salmonids by Northern Squawfish (*Ptychocheilus oregonensis*) from the Columbia River

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Abstract

Maximum daily consumption rate (Cm,, as ration or number) of northern squawfish (*Ptychocheilus oregonensis*) from the Columbia River, increased exponentially as a function of temperature. Predator weight did not explain a significant independent proportion of variation in Cm,,. The mean maximum daily ration, determined from replicate *ad libitum* feeding on juvenile Pacific salmon (*Oncorhynchus spp.*), was 0.45, 0.67, 3.51, and 4.51 $cg \cdot g^{-1}$ at 8.0, 12.5, 17.0, and 21.5°C, respectively. To quantify the temperature dependent consumption relation for use in simulation modeling, replicate $C_{max}$ data within the preferred temperature range were fit to exponential and exponential sigmoid models. Based on a knowledge of thermal relations of northern squawfish, hypothetical Cm,, data at temperature extremes were combined with our results: this enabled us to fit gamma and Thornton and Lessem (1978) models over the entire environmental temperature range (0-27°C) observed in the Columbia River.

## Introduction

Northern squawfish, *Ptychocheilus oregonensis* (Richardson), is native to the Columbia River and is a major predator of out-migrating juvenile salmonids. Predation by northern squawfish is especially high where salmonids are abundant and concentrated (Brown and Moyle 1981); e.g., associated with hatchery releases (Thompson 1959) and below dams during migration periods (Ebel 1977). In John Day Reservoir, northern squawfish had the highest per predator rates of salmonid consumption of four major fish predators (Vigg et al. 1988), and was the most abundant piscivore -- thus accounting for the highest losses of salmonid juveniles (Rieman et al. 1988).

The relation between maximum consumption rate and temperature is fundamental for understanding the predation dynamics of northern squawfish. It is well known that evacuation rate of northern squawfish increases greatly with increasing temperature (Falter 1969; Steigenberger and Larkin 1974; Beyer et al. 1988). but prior to this study, the maximum number and ration of salmonids that northern squawfish could consume at various temperatures was unknown. Daily ration is defined as the size of the daily meal expressed as a percentage of predator body weight, i.e., $cg \cdot g^{-1} \cdot d^{-1}$ (Ricker 1946). Maximum consumption ($C_{max}$) is the physiological maximum daily ration which determines the ultimate upper bound on the growth potential of a fish (Stewart and Binkowski 1986). Quantification of maximum consumption as a function of temperature is prerequisite to modeling predator-prey dynamics using either the bioenergetics approach (Kitchell 1983; Rice et al. 1982) or the empirical approach based on the functional response of predation rate to prey density (Vigg 1988).

The objectives of this paper were to quantify the maximum daily consumption of northern squawfish with respect to temperature and predator size, and to develop a model of maximum consumption for the entire environmental temperature range of northern squawfish habitats. Maximum consumption was evaluated in terms of number and ration of salmonid juveniles consumed per day by northern squawfish fed to satiation (i.e., physiological maximum). Comparative data on *in situ* stomach contents and thermal relations of this predator at the upper and lower extremes were used to hypothesize the probable relation outside the range of our experimental data.

## Materials and Methods

Northern squawfish were collected from the Columbia River, John Day Reservoir, during April-October 1987 and July-September 1988. The primary collection method was electroshocking from a 6.4-m boat. Northern squawfish were also collected using hook and line angling from the face of McNary Dam. The thermal history of the habitat sampled was obtained from the US Army Corps of Engineers records (Brad Eby, U.S. Army Corps of Engineers, Walla Walla District, Washington, Personal Correspondence). The fish were transported to, and maintained at the U.S. Fish and Wildlife Service (USFWS), Columbia River Field Station, Cook, Washington. The northern squawfish were fed a maintenance diet of juvenile salmon (*Oncorhynchus tsyawytscha,* and *O. kisutch*) reared at the USFWS Little White Salmon-Willard National Fish Hatchery.

Laboratory Facilities

Tests were conducted using 12 circular fiberglass tanks (1365 l), in a recirculating system consisting of a biofilter, sand filter, ultraviolet lights, and thermostatically controlled heaters. General operational procedures are documented in Lucchetti and Gray (1988). The system was contained in a laboratory having air temperature and photoperiod regulation. The well-water supply varied about 6°C in temperature annually (4-10°C), had a pH of about 7.0, and total hardness of 20 $mg \cdot l^{-1}$. The proportion of water reused could be varied from 0-100% and was held below approximately 10%.

Experimental design

The protocol of the experiments was similar to that summarized by Stewart and Binkowski (1986). Predator weight and temperature were treatments of the experiment which were systematically varied. Duration of the feeding experiment (48 h), prey species composition and size range, diurnal photoperiod (12 h), and light intensity (1.5 lux) were kept constant Both number (6) and weight (≈ 5% coefficient of variation) of northern squawfish per tank was held constant to standardized feeding behavior.

Tests were designed to encompass the hypothesized preferred thermal range of northern squawfish (10-21°C), and be within the range of temperatures observed in the Columbia River (0-27°C). Tests were scheduled for four target temperatures, i.e., 8.0, 12.5, 17.0, and 21.5°C (Fig. 1). We defined *acclimization period* as the 60 day interval in the natural environment prior to acclimation period: and *acclimation period* as the approximately 30 day interval in the laboratory tanks prior to the test (2 days duration). Achieved test temperatures were within 0.4°C of the target temperatures.

In order to obtain size-specific $C_{max}$ relationships, a size range of northern squawfish (Fig. 2A), stratified by weight group were tested. The size of northern squawfish we tested (> 500 g) was based on the predator size at which prey fish became predominant in the diet. Poe et al. (1988) found that northern squawfish began feeding on salmonids at a length of about 250 mm (≈ 190 g), and fish were a major constituent of the diet at a length of about 350 mm (≈ 560 g). When possible, four replicates (group of six fish) of the following sizes were tested at each temperature: (1) 501-1100 g; (2) 1101-1500 g; and (3) 1501-2000 g. For each replicate, the total grams of prey consumed per total grams of predator made one observation: thus each observation represents a mean value for the six individuals. The six fish for a given test were as uniform in weight as possible: i.e., the 58 test groups had a mean coefficient of variation in weight of 4.3% .

Because of problems in collecting sufficient numbers of large predators during late summer, we were unable to achieve a balanced experimental design. The number of replicates for each test temperature, stratified by predator size is presented in Table 1. The northern squawfish collected during August, 1987 (experiment 4, 21.5°C) were in poor condition, possibly because of post-spawning or temperature-related stress; and the test fish experienced high mortality (48%) during the acclimation period. Therefore we considered the results from this test as invalid, and we repeated this test temperature

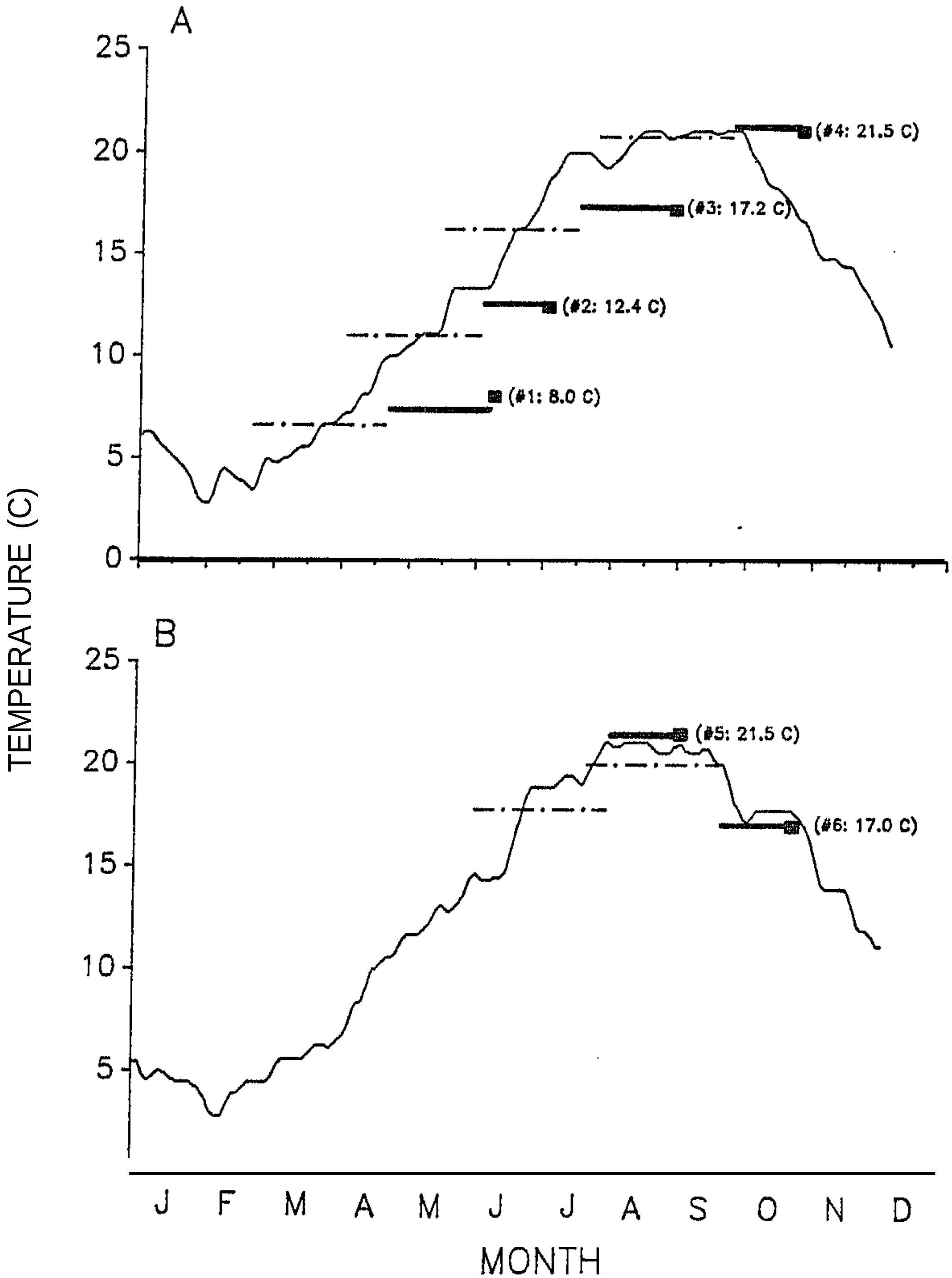


Fig. 1. Experimental temperatures (A, 1987; and B, 1988): river water (fine solid line), acclimization (dashed-dotted), acclimation (bold-solid) and test (solid square). Mean test temperature values are in parentheses.

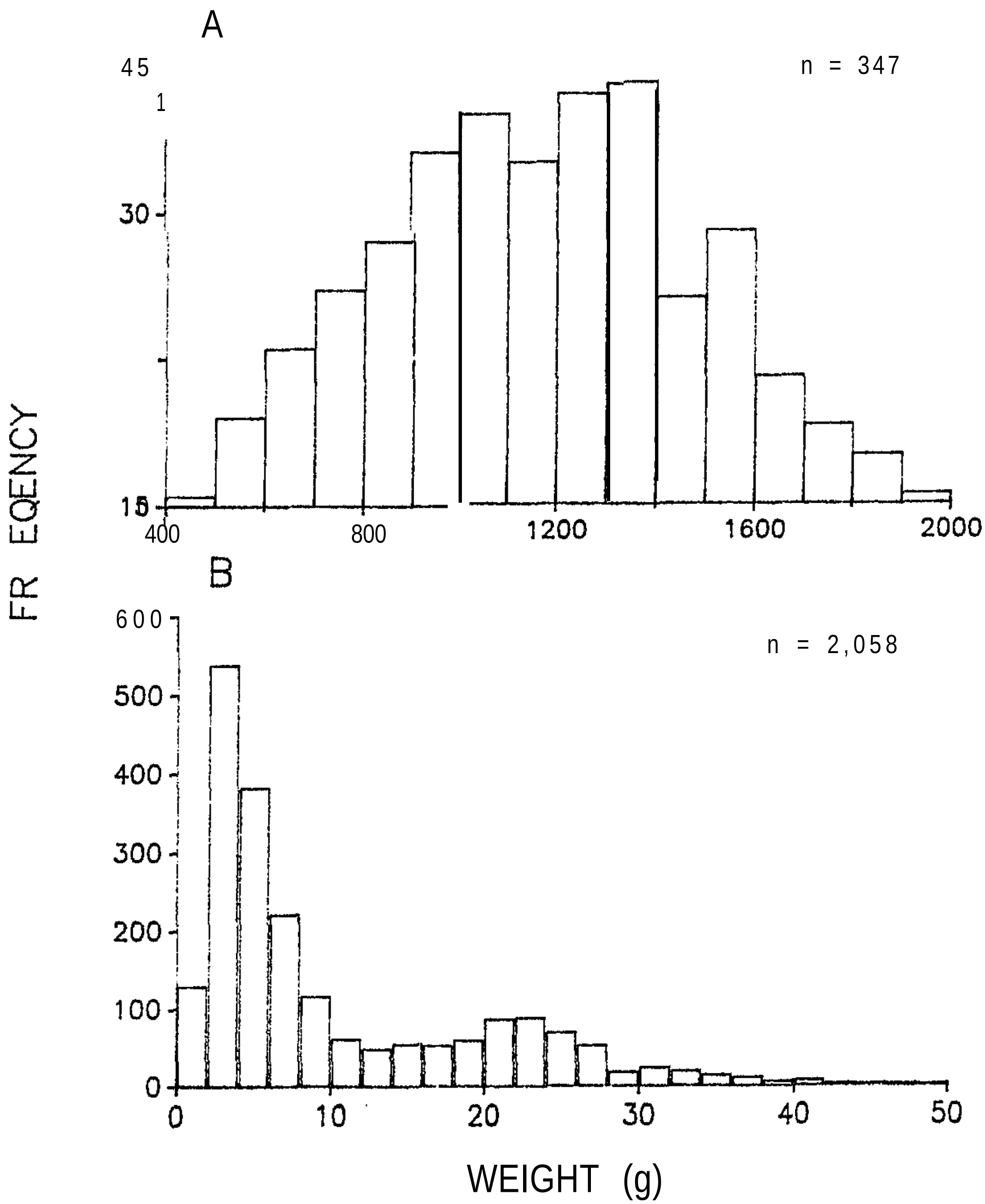


Fig. 2. Size frequency distributions (weight, g) of northern squawfish (A), and juvenile salmon (B).

Table 1. Number of replicates for each treatment of the maximum consumption experiment.

| Predator Size Group | | Test Number (Temperature, °C) | | | | | | Sum |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | |
| Weight (g) | Length (mm) | (8.0) | (12.5) | (17.0) | (21.5[a]) | (21.5) | (17.0) | |
| 501-1100 | 358-432 | 4 | 4 | 4 | 5 | 6 | 7 | 30 |
| 1101-1500 | 433-477 | 4 | 4 | 6 | 5 | 4 | 5 | 28 |
| 1501-2000 | 478-522 | 4 | 4 | 0 | 2 | 2 | 0 | 12 |
| Total | | 12 | 12 | 10 | 12 | 12 | 12 | 70 |

[a] Invalid test due to the poor condition (low consumption, high mortality) of the northern squawfish.

(21.5°C, experiment 5) in 1988. The mortality at 21.5°C for experiment 5 was low (0.8%) and the condition of the fish was good -- therefore the results from experiment 4 were omitted, and replaced by experiment 5. The 17.0°C treatment was also repeated in 1988 (experiment 6) because no large fish 0 1500 g) were tested in experiment 3: during 1988, however, we were again unable to collect enough large northern squawfish for testing. Overall, we had 5 valid tests at 4 different temperatures: i.e., a total 58 replicate tests of 6 predators each were used for the analysis.

Test Procedure

Northern squawfish were sorted by weight, and groups of six fish were randomly placed in the 12 tanks, and allowed to acclimate to the test temperature for at least one month prior to tests. Only healthy, actively feeding fish were used for tests. The test fish were deprived of food for sufficient time, dependent upon temperature, to empty the gut; calculated from an evacuation rate regression equation (Beyer et al. 1988). During the tests, northern squawfish with initially empty stomachs were fed a size range of juvenile coho and chinook salmon (Fig. 2B) at the start and every 4 h over a 48-h period (i.e., 14 feedings). The final feeding was 47.5 h from the start. Preyfish weights were measured when introduced into the tanks: preyfish not eaten were weighed at the end of the test (± 0.1 g). Individual northern squawfish weights, minus the weight of stomach contents, were measured (± 1.0 g) at the end of the experiment. Maximum percent ration of the sample was calculated as total weight of prey fish consumed (cg) per total predator weight (g) per 24 h.

Water temperature was continuously monitored in each test tank with calibrated recording meters. Dissolved oxygen ($mg \cdot l^{-1}$) was measured daily with a calibrated YSI* meter. Gross mineral, nutrient, and trace metal analyses were conducted once on the water source prior to the study (Table 2). Samples were taken on 9 March 1987, and analyses were conducted by Laucks Laboratories, Inc., Seattle, Washington.

Modeling Cmax -- 8 to 21.5°C Temperature Range

The maximum consumption data, within the 8.0-21.5°C range, were fitted to two non-linear functions of temperature. First, an exponential model:

$$(1) \qquad C_{max} = a\, e^{bT}$$

where; $C_{max}$ is maximum consumption rate as either daily ration ($cg \cdot g^{-1}$) or number consumed ($smolts \cdot predator^{-1}$), T is temperature (°C), and a and 4 are empirical constants. Thus, the daily $C_{max}$ is represented as a proportion of predator weight or number consumed per predator, and an exponential function of temperature (Brett 1971; Kerr 1971; Elliot 1976). The coefficients were fitted from the data using least-squares multiple regression:

* The mention of a product name does not constitute endorsement by the U.S. Government or the Oregon Department of Fish and Wildlife.

Table 2. Chemical constituent analysis of the well water source used for the maximum consumption experiments, at the USFWS Columbia River Field Station, Cook, Washington.

| Constituent (units) | Measurement ($mg \cdot l^{-1}$, unless specified) |
|---|---|
| pH (log scale @ 25 C) | 7.1 |
| Specific Conductance ($\mu ohoms \cdot cm^{-1}$ @ 25 C) | 73 |
| Total Hardness | 28 |
| Total Hardness (as $CaCO_3$) | 37 |
| Potassium | 0.9 |
| Sulfate (as $SO_4$) | < 1.0 |
| Sodium | 4.7 |
| Calcium | 9.0 |
| Chloride | < 1.0 |
| Manganese | < 0.002 |
| Zinc | 0.003 |
| Copper | < 0.002 |
| Silver | < 0.002 |
| Mercury | < 0.001 |
| Lead | < 0.01 |
| Cadmium | < 0.002 |

$$\ln C_{max} = \ln a + (bT). \tag{2}$$

Second, an exponential sigmoid model was fit to the data using least-squares non-linear regression:

$$C_{max} = a / \{1 + b\ e^{(cT)}\} \tag{3}$$

where: $T$ is environmental temperature, a is asymptotic (maximum) consumption, and a, $b$, and c are empirical constants.

<u>Modeling Cmax -- 0-27°C Temperature Range</u>

Three different algorithms were used to model $C_{max}$ over the entire temperature range which exists in northern squawfish habitats, i.e., 0-27°C. In order to model the relations beyond the range of our experimental data, we used the mean values from our experiments on the 8 to 21.5°C range and preferred temperatures observed by other workers, and made assumptions on decreasing consumption rates as temperature approached the upper and lower incipient lethal levels; i.e. no consumption at 0-1°C, and none at 27-30°C. We also assumed that 21.5°C is the optimum temperature for peak consumption. First, we fit the mean experimental and hypothetical data to the gamma function (L.J. Bledsoe, Center for Quantitative Science, University of Washington, Personal Correspondence):

$$C_{max} = \{(T/T_o)^a\}\ \{e^{((a/b)\ (c-((T/T_o)\hat{}b)))}\} \tag{4}$$

where, $C_{max}$ is maximum consumption rate as either daily ration ($cg \cdot g^{-1}$) or number consumed ($smolts \cdot predator^{-1}$) standardized to one, T is environmental temperature (°C), To (21.5°C) is the optimum temperature for peak consumption, and a, 4 and c are empirical constants.

Secondly, we used the biological-rate temperature algorithm of Thornton and Lessem (1978) :

$$C_{max} = K_A(T) * K_B(T) \quad ; \tag{5}$$

and,

$$K_A(T) = \frac{K_1\ e^{v_1\ (T-T_1)}}{1 + K_1\ \{e^{v_1 (T-T_1)}-1\}} \quad ;$$

and,

$$K_B(T) = \frac{K_2\ e^{v_2\ (T-T_2)}}{1\ t\ K2\ \{e^{v_2 (T-T_2)}-1\}} \quad ;$$

where: $C_{max}$ is maximum consumption rate standardized to one, T is environmental temperature (°C), $T_1$ is the temperature at lower consumption threshold, $T_2$ is temperature at upper consumption threshold, $K_1$ is the rate multiplier near lower threshold temperature, $K_2$ is the rate multiplier near upper threshold temperature, $v_1$ is the empirical lower specific rate coefficient,

coefficient, $v_2$ is the empirical upper specific rate coefficient. See Thornton and Lessem (1978) for a detailed derivation of coefficients.

Third, a polynomial model:

$$(6) \qquad C_{max} = a(T)^2 \text{ t } b(T)^3 \text{ t } c(T)^4 \text{ t } d(T)^5 \text{ t } e(T)^6$$

where; T is environmental temperature (°C), the Y-intercept is zero, and a, *b*, c, *d* and *e* are empirical constants.

Wet:dry weight relations

Juvenile coho or chinook salmon were randomly collected from each of three size groups (mean weight in parentheses): five small (4.3 g) coho salmon, 25 medium (13.3 g) chinook salmon, and 30 large (26.9 g) coho salmon. Each individual fish was killed, blotted dry, and weighed to the nearest 0.001 g using a Mettler* PE160 balance. At the end of each test, one northern squawfish from each of the three size groups (i.e., 500-1100, 1101-1500, and > 1500 g) was weighed to the nearest gram, labeled, and frozen for later dry weight determination.

The fresh juvenile salmon and the thawed northern squawfish were cut into sections and blended separately to a homogeneous mixture in a Waring Commercial Blendor*. The mixture was then re-weighed to the nearest 0.001 g prior to drying. Each blended fish was assigned a separate ceramic crucible and dried at 60°C for at least six days or until the weight was constant for three consecutive weighings -- whereupon the final dry weight measurement was made. Equations for converting wet to dry weight were calculated using simple least-squares linear regressions with a y-intercept of zero.

## Results

In all experiments combined, 341 northern squawfish, averaging 1148 g, consumed 2363 juvenile salmonids, averaging 8.0 g; this translates to a maximum daily consumption rate of 2.4 $cg \cdot g^{-1}$ or 3.5 salmonids-predator-l. However, maximum consumption rate was significantly related to temperature, and varied to some extent by predator size. The mean maximum daily ration ($cg \cdot g^{-1}$) increased as a function of temperature from 0.47 at 8.0°C, to 4.50 at 21.5°C (Table 3; Fig. 3A). Likewise, the mean number consumed increased from 0.52 at 8.0°C, to 7.01 salmonids-predator-l at 21.5°C (Fig. 3B). The maximum daily ration data versus temperature were fitted to an exponential equation (equation 1):

$$C_{max} = 0.0544\, e^{(0.2095\, T)}$$

where; $C_{max}$ is the maximum daily ration, and T is the temperature (°C). To better describe the known leveling-off of maximum daily ration at optimum temperature, an exponential sigmoid function was fit to the data (equation 3):

* The mention of a product name does not constitute endorsement by the U.S. Government or the Oregon Department of Fish and Wildlife.

Table 3. Maximum consumption statistics (mean percent daily ration and number per predator) of salmonid prey by northern squawfish predators.

| Predator Weight Range (g) | Mean Consumption Statistic (sample size) | Temperature (°C) | | | |
|---|---|---|---|---|---|
| | | 8.0 | 12.5 | 17.0[a] | 21.5 |
| 501-1100 | Ration | 0.79 | 0.86 | 3.71 | 4.64 |
| | Number | 0.52 | 1.25 | 3.97 | 6.38 |
| | (n) | (4) | (4) | (11) | (6) |
| 1101-1500 | Ration | 0.29 | 0.68 | 3.31 | 5.42 |
| | Number | 0.40 | 1.27 | 4.58 | 8.50 |
| | (n) | (4) | (4) | (11) | (4) |
| 1501-2000 | Ration | 0.27 | 0.48 | | 3.48 |
| | Number | 0.46 | 1.00 | | 7.00 |
| | (n) | (4) | (4) | (0) | (2) |
| Mean by Tank | Ration | 0.47 | 0.69 | 3.39 | 4.50 |
| | Number | 0.52 | 1.17 | 4.23 | 7.01 |
| | (n) | (11) | (12) | (22) | (12) |

[a] Mean of two experiments.

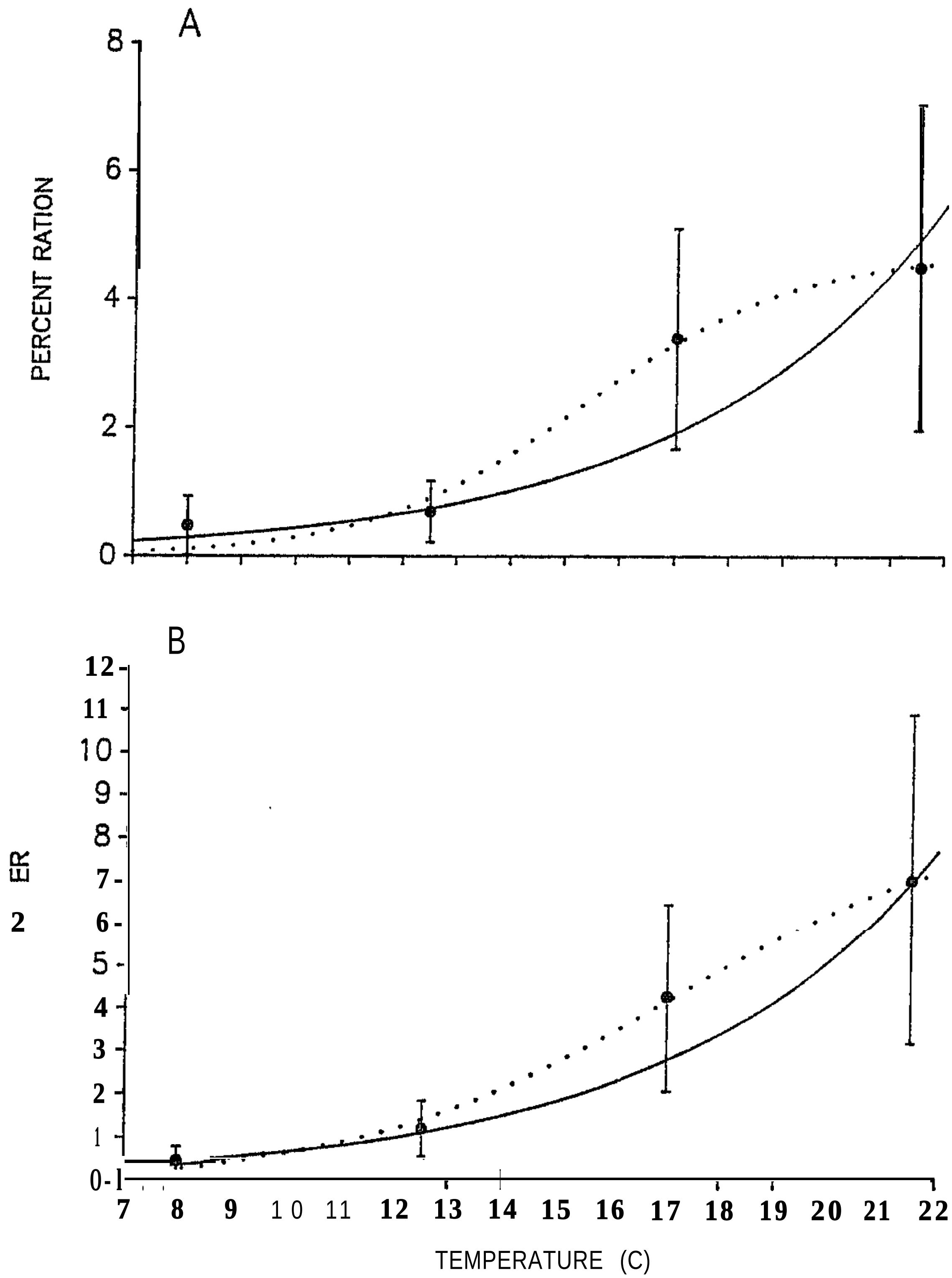


Fig. 3. Waximum consumption of juvenile salmonids by northern squawfish as a function of temperature, fitted to exponential (equation 1, solid line) and exponential sigmoid (equation 3, dotted line) models -- for daily percent ration (A) and number consumed (B). Mean values of maximum consumption (solid circles: n = 11-22) are bounded by one standard deviation (bars).

$$C_{max} = 4.7377 / \{(1 + 7.7760\ b)\ e^{(-.5069\ T)}\}$$

Coefficients for the temperature models in terms of number of salmonids·predator$^{-1}$ are given in Table 4.

No significant bivariate relation was observed between northern squawfish weight and replicate $C_{max}$ measurements ($P > 0.05$); however mean $C_{max}$, generally decreased with increasing predator weight (Fig. 4A). To test the efficacy of a multiple regression approach (e.g., Wootton et al. 1980), the $C_{max}$ residuals (ration and numbers) from both temperature models (equations 1 and 3) were regressed on northern squawfisb weights. Using weight as an additional indpenndant variable did not explain a significant proportion of variability ($R^2$ = .0003-.025).

Model: maximum daily ration

Gamma (equation 4), Thornton and Lessem (1978) biological rate algorithm (equation 5), and polynomial (equation 6) models were fit to mean maximum consumption rates over the entire environmental temperature range, i.e., 0-27°C (Table 4). These relations were derived from our maximum consumption experiments, a knowledge of in *situ* consumption rates, the upper thermal relations of northern squawfish, and assumptions of the cessation of feeding at high and low thermal extremes (Fig. 5).

Wet : dry weight relations

The linear regression equations for the combined coho salmon and chinook salmon (equation 7), and the northern squawfish (equation 8) were:

(7) $$D_C = 0.218\ (W_C), \qquad (n = 60,\ R^2 = 0.99):$$

(8) $$D_S = 0.306\ (W_S), \qquad (n = 12,\ R^2 = 0.99);$$

where: $D_C$ is the dry weight of the combined salmon, $W_C$ *is* the wet weight of the combined salmon, $D_S$ is the dry weight of the northern squawfish, and $W_S$ is the wet weight of the northern squawfish.

## Discussion

We found that temperature was the overriding variable affecting the maximum consumption rate of northern squawfish. The exponential sigmoid (equation 3) was the most realistic model of temperature-dependency of consumption rate because it incorporates the asymptotic Cm,, at optimum temperature. We are assuming that the optimum is near the highest temperature we tested, but further experiments will be necessary to refine optimum temperature for consumption and growth. Insignificant additional variability in $C_{max}$ was explained by including predator weight as a predictor variable. However, in general, mean ration decreased with increasing predator weight. This finding is inconsistent with mean consumption rates in John Day Reservoir (Vigg et al. 1988); i.e., in that study mean daily ration of northern

Table 4. Coefficients for five models of maximum. consumption rate (ration and number) as a function of temperature.

| Temp. Range, Model | equation from text[a] | Coefficients (Statistic) | Maximum Consumption Measure: Standardized[b] Ration | Standardized[b] Number | Actual data Ration | Actual data Number |
|---|---|---|---|---|---|---|
| **8-21.5 °C:** | | | | | | |
| Exponential | 1 | a | -- | -- | 0.0544 | 0.0818 |
| | | b | -- | -- | 0.2095 | 0.2066 |
| | | (n) | -- | -- | 57 | 57 |
| | | ($R^2$) | -- | -- | 0.520 | 0.593 |
| Sigmoid | 3 | a | -- | -- | 4.7377 | 8.4897 |
| | | b | -- | -- | 7.7760 | 6.0781 |
| | | c | -- | -- | -.5069 | -.3545 |
| | | (n) | -- | -- | 57 | 57 |
| | | ($R^2$) | -- | -- | 0.512 | 0.535 |
| 0-27 °C: | | | | | | |
| Gamma | 4 | $T_o$ | 21.5 | 21.5 | 21.5 | 21.5 |
| | | a | 2.8227 | 3.3627 | 2.9662 | 3.3994 |
| | | b | 13.7319 | 13.7628 | 13.5696 | 13.7435 |
| | | c | 1.0 | 1.0 | 8.0719 | 8.9074 |
| | | (n) | 6 | 6 | 6 | 6 |
| | | ($R^2$) | 0.979 | 0.997 | 0.981 | 0.997 |
| Thornton & Lessem (1978) | 5 | $T_1$ | 0 | 0 | -- | -- |
| | | $T_2$ | 27 | 27 | -- | -- |
| | | $K_1$ | 0.001 | 0.001 | -- | -- |
| | | $K_2$ | 0.01 | 0.01 | -- | -- |
| | | $v_1$ | 0.4944 | 0.4521 | -- | -- |
| | | $v_2$ | 1.8380 | 1.8381 | -- | -- |
| | | (n) | 6 | 6 | -- | -- |
| | | ($R^2$) | 0.965 | 0.983 | -- | -- |
| Polynomial | 6 | a | .01318 | .01635 | .05904 | .11405 |
| | | b | -.00387 | -.00460 | -.01735 | -.03209 |
| | | c | .00040 | .00046 | .00181 | .00318 |
| | | d | -.00002 | -.00002 | -.00007 | -.00001 |
| | | e | 2.2E-7 | 2.43-7 | 9.93-7 | 1.7E-6 |
| | | (n) | 6 | 6 | 6 | 6 |
| | | ($R^2$) | 0.959 | 0.953 | 0.959 | 0.953 |

[a] equations:

Exponential $C_{max} = a\ e^{bT}$

Sigmoid $C_{max} = 21.5 / \{ (1+b)\ e^{(cT)} \}$

Gamma $C_{max} = \{ (T/T_o)^{a} \} \{ e^{((a/b)\ (c-((T/T_o)\hat{\ }b)))} \}$

Thornton and Lessem (1978) $C_{max} = K_A(T) * K_B(T)$

and, $$K_A(T) = \frac{K_1\ e^{v_1 (T-T_1)}}{1 + K_1\ \{ e^{v_1 (T-T_1)} - 1 \}},$$

and, $$K_B(T) = \frac{K2\ e^{v_2 (T-T_2)}}{1\ t\ K2\ \{ e^{v_2 (T-T_2)} - 1 \}}.$$

Polynomial $Cmax = a(T)^2\ t\ b(T)^3\ t\ c(T)^4\ t\ d(T)^5\ t\ e(T)^6$

[b] Standardized data $= X_i/X_{max}$

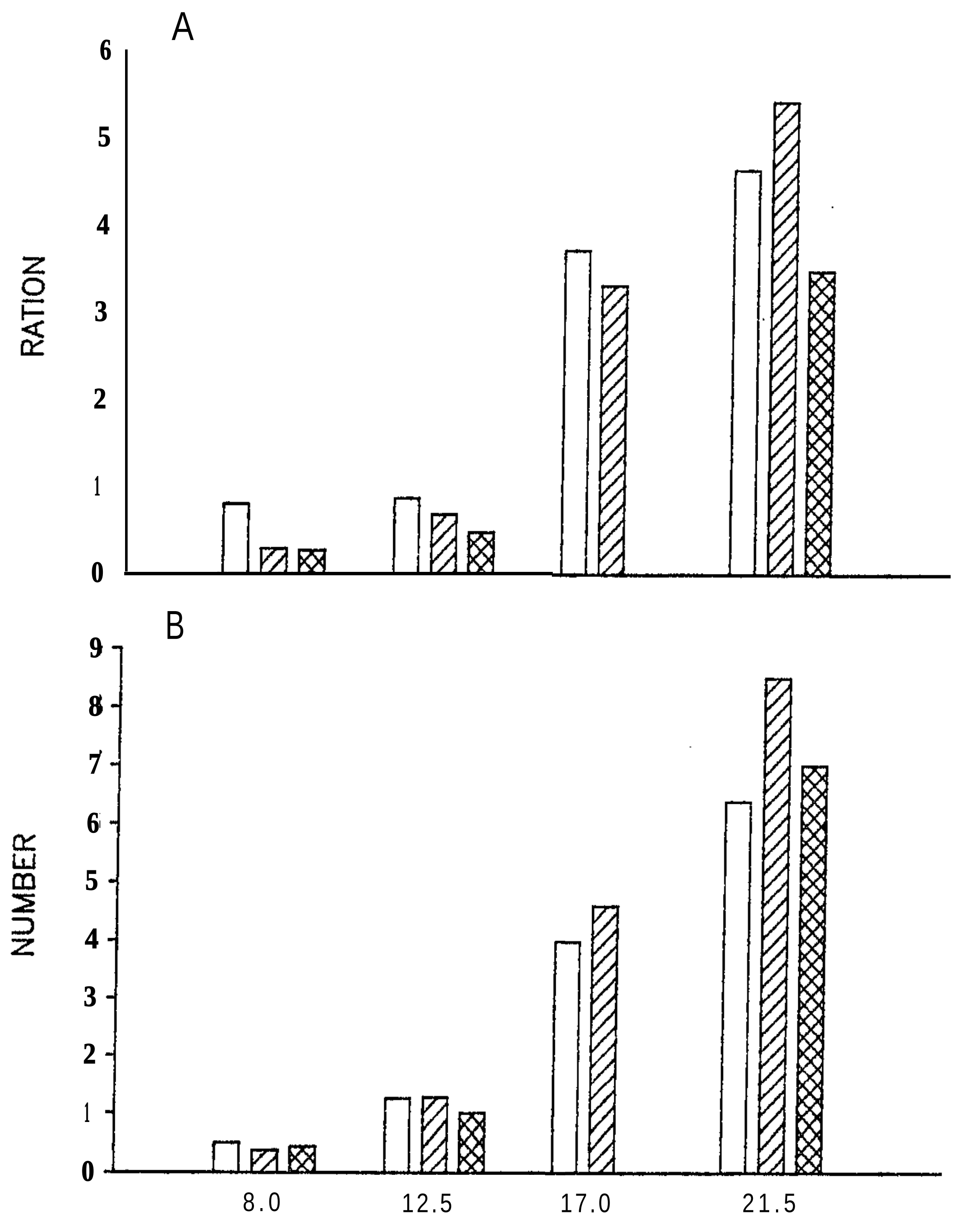


Fig. 4. Maximum consumption of juvenile salmonids by northern squawfish stratified by temperature and predator size group (small, clear; medium, diagonal; and large, cross-hatched) -- for daily percent ration **(A)** and **number** consumed **(B)**.

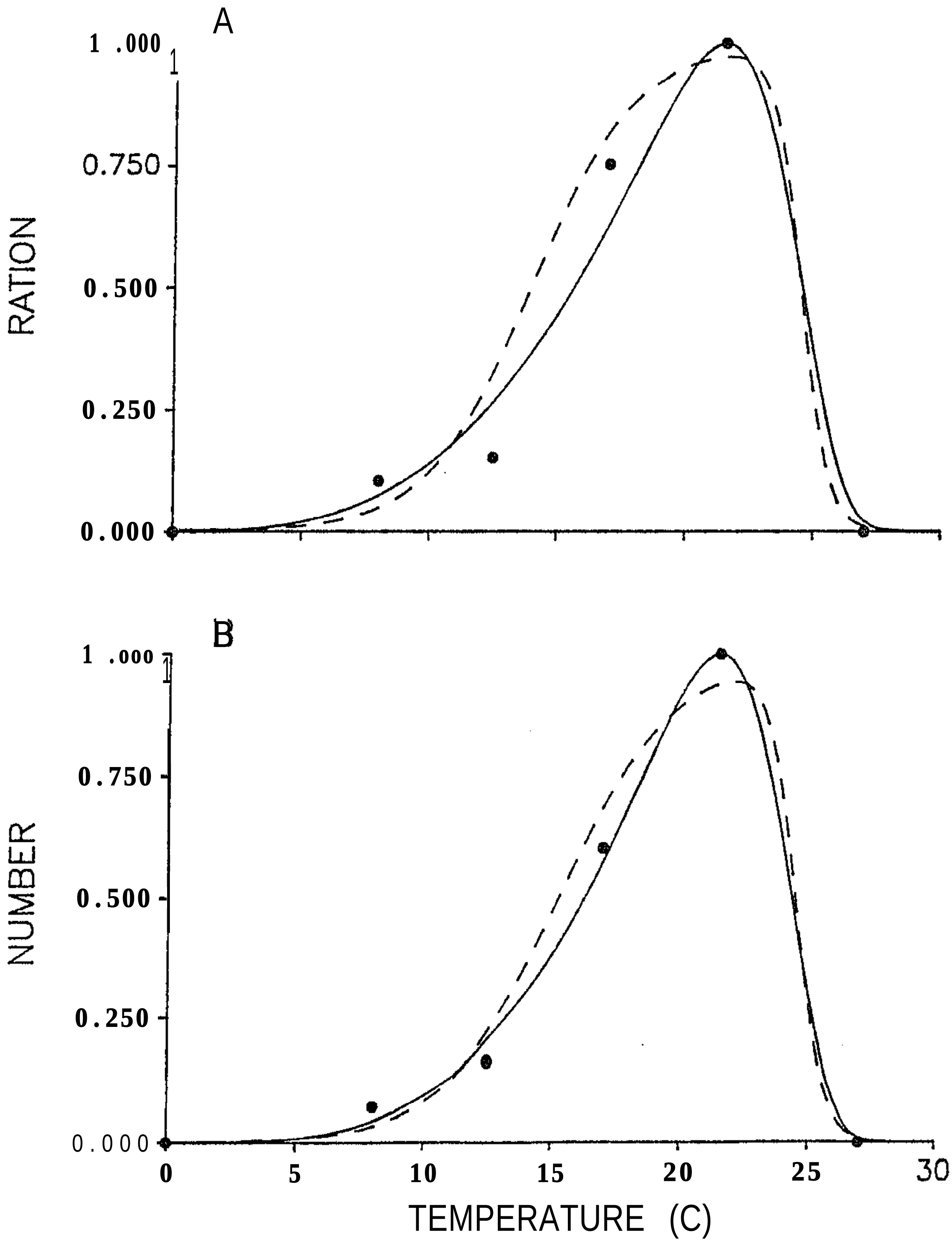


Fig. 5. Gamma (solid line), and Thornton and Lessen (1978) (dashed line) models for maximum consumption in terms of (A) daily ration ($cg \cdot g^{-1}$), and (B) number per predator -- standardized to one.

squawfish increased with predator size. This may be xp lained by the fact that the mean ration in John Day Reservoir (< 1.5 $cg \cdot g^{-1}$) was considerably below the physiological rations determined here, and other factors (e.g., food availability, and behavioral dominance relationships) are probably constraining consumption in nature.

Brett (1979) summarized the factors which affect maximum consumption: (1) duration of a given feeding (satiation time); (2) individual meal size (stomach capacity); (3) time between meals (feeding interval); and (4) interaction among the factors. Temperature and consumer size are usually the most important abiotic and biotic determinants of these factors; Cm, increases with temperature within the range a species normally inhabits and decreases with fish size (Brett 1979). Wootton et al. (1980) presented various models for predicting maximum daily consumption rates of fishes: four models using predator body weight as the independent variable: five models using temperature: and two multivariate (weight and temperature) models. They concluded a bivariate power model for weight, and multiple *regression* power model incorporating weight and temperature had the best empirical fits for two species, *Gasterosteus aculeatus,* and *Phoxinus phoxinus.* Similarly, Elliot (1975) found a multivariate (weight and temperature) power relation was an appropriate model for brown trout (*Salmo trutta*).

Thus, the conclusions of previous studies on other predaceous species are not in agreement with our results that indicated an exponential sigmoid model (temperature-c,,,) was most appropriate for northern squawfish within the preferred temperature range. The lack of a significant relation between predator weight and $C_{max}$ may be due to the variability of consumption rate in weight replicates, and interactions between temperature and weight effects. Mean $C_{max}$, stratified by weight group and temperature, generally showed the expected decreasing ration with increasing predator weight (Fig. 4A). This size relation, however was not consistent at all temperatures: i.e., the medium sized group at 21.5°C was anomalous. Another factor affecting the weight relation in our experiments was the exclusion of northern squawfish weighing < 500 g; these small, mostly non-piscivorous northern squawfish may have higher metabolic requirements and thus exhibit higher daily rations.

Maximum daily ration for many fishes increases with increasing temperature to a maximum near the fishes' preferred temperature, and subsequently declines to near zero just below maximum lethal temperature (Elliot 1976; Kitchell et al. 1977; Brett 1983; Bevelhimer et al. 1985; Stewart and Binkowski 1986). Northern squawfish exhibited 100, 50, and 0% survival at 26.4, 29.3, and 32.0°C, respectively, when acclimated at 18.9-22.2°C (Black 1953). Thus their incipient upper lethal temperature is about 29°C (Brown and Moyle 1981). Based on field observations, northern squawfish prefer temperatures of about 16-22°C (Dimick and Merryfield 1945). Northern squawfish digested fish at rates of 5, 14, and 40-50% per hour at temperatures of 4-6, 10-12, and 24°C, respectively (Steigenberger and Larkin 1974). Falter (1969) and Beyer et al. (1988) also observed increases in digestion rate with temperature. From these data we predict temperature-specific $C_{max}$ will be near zero at 0°C, be very low at 4°C, will peak at 20-24°C, and be near zero at 27°C. Temperature of McNary Dam discharge ranges from about 0.5 to 23.5°C; sub-surface temperature measurements in the reservoir were significantly higher, especially in backwater areas (≈27°C). The gamma model provided a slightly better fit, over the entire environmental temperature range, than either the Thornton and Lessem (1978) or the polynomial models. Diana (1987) used a multivariate model for maximum consumption rate of northern pike (*Esox lucius*), which incorporated a power function of predator weight and a polynomial function of temperature. We do not consider the polynomial model valid because it has the undesirable characteristics of being purely empirical with no underlying theoretical basis, of having coefficients with no biological meaning, and of exhibiting unrealistic cyclic behavior at the upper and lower extremes.

We analyzed the relation between temperature and $C_{max}$ both in terms of daily ration and number consumed per northern squawfish. In applying our results to predation models, we believe the use of ration as the measure of $C_{max}$ is usually more appropriate because it standardizes the weight of salmonid prey consumed per unit weight of predator. In nature, both the size of predator and prey can vary substantially on a seasonal or spatial basis, therefore erroneous predictions of $C_{max}$ could be derived if number were used as the criterion variable (unless the mean weights of the northern squawfish and salmonid prey were very similar to our test fish). For example, extremely high numbers of salmon fry (> 200 per predator) have been observed in the stomachs of northern squawfish in a backwater below Little White Salmon Hatchery near Cook, Washington (U.S. Fish and Wildlife Service, Unpublished Memo, 1951). Our results are presented in wet weight; however, for greater utility, we present conversion factors of wet to dry weight for both adult northern squawfish and juvenile salmon.

Both the functional response relation (Vigg 1988) and maximum consumption rate relation are central to prototype predation models for the John Day Reservoir (Beamesderfer et al. In Press) and the Columbia River System (L.J. Bledsoe, Center for Quantitative Science, University of Washington, Personal Correspondence). Modeling predator-prey dynamics may be the only practicable way to quantify the system-wide losses to predation and for understanding the factors affecting predation in a river as large and perturbed as the Columbia.

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## References

Beamesderfer, R.C., B.E. Rieman, L.J. Bledsoe, and S. Vigg. In Press. Management implications of a model of predation by a resident fish on juvenile salmonids migrating through a Columbia River reservoir. N. Am. J. Fish. Manage.

Bevelhimer, M.S., R.A. Stein, and R.F. Carline. 1985. Assessing significance of physiological differences among three esocids with a bioenergetics model. Can. J. Fish. Aquat. Sci. 42:57-69.

Beyer, J.M., G. Lucchetti, and G. Gray. 1988. Digestive tract evacuation in the northern squawfish (*Ptychocheilus oregonensis*). Can. J. Fish. Aquat. Sci. 45:548-553.

Black, E.C. 1953. Upper lethal temperature of some British Columbia freshwater fishes. J. Fish. Res. Board Can. 10:196-210.

Brett, J.R. 1971. Satiation time, appetite, and maximum food intake of sockeye salmon (*Oncorhynchus nerka*). J. Fish. Res. Board Can. 28:409-415.

1979. Environmental factors and growth. pages 599-675 *in* W.S. Hoar, D.J. Randall, and J.R. Brett (eds.) Fish Physiology, Vol. VIII: bioenergetics and growth. Academic Press, New York, NY.

1983. Life energetics of sockeye salmon, *Oncorhynchus nerka*. Pages 29-63 in W.P. Aspey and S.I. Lustick (eds.) Behavioral energetics: the cost of survival in vertebrates. Ohio State Univ. Press. Columbus, Ohio.

Brown L.R., and P.B. Moyle. 1981. The impact of squawfish on salmonid populations: a review. N. Am. J. Fish. Manage. 1:104-111.

Diana, J.S. 1987. Simulation of mechanisms causing stunting in northern pike populations. Trans. Am. Fish. Soc. 116: 612-617.

Dimick, R.E., and F. Merryfield. 1945. The fishes of the Willamette River system in relation to pollution. Oregon State College, Agricultural Experimental Station Bulletin 20, Corvallis, Oregon, USA.

Ebel, W. 1977. Panel 2: Fish passage problems and solutions - major passage problems. Pages 33-39 *in* E. Schwiebert (ed.) Columbia River salmon and steelhead. American Fisheries Society, Special Publication No. 10. Washington, D.C.

Elliot, J.M. 1975. Number of meals in a day, maximum weight of food consumed in a day, and maximum rate of feeding for brown trout, *Salmo trutta* L. Freshwat. Biol. 5:287-303.

1976. The energetics of feeding, metabolism and growth of brown trout (*Salmo trutta* L.) in relation to body weight, water temperature and ration size. J. Animal Ecology 45:923-948.

Falter, C.M. 1969. Digestive rates and daily rations of northern squawfish in the St. Joe River, Idaho, Doctoral Dissertation, University of Idaho, Moscow, Idaho, USA.

Kerr, S.J. 1971. Prediction of fish growth efficiency in nature. J. Fish. Res. Board Can. 28:809-814.

Kitchell, J.F. 1983. Energetics. Pages 312-338 *in* P.W. Webb and D. Weihs, editors. Fish biomechanics. Praeger, New York.

Kitchell, J.F., D.J. Stewart, and D. Weininger. 1977. Applications of a bioenergetics model to yellow perch (*Perca flavescens*) and walleye (*Stizostedion vitreum vitreum*). J. Fish. Res. Board Can. 34:1922-1935.

Lucchetti, G.L., and G.A. Gray. 1988. Prototype water reuse system. Prog. Fish-Cult. 50:46-49.

Poe, T.P., H.C. Hansel, S. Vigg, D.E. Palmer, and L.A. Prendergast. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia reservoir Part I: Feeding ecology during the salmonid smolt out-migration. Pages 13-55 in T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Rice, J.A., J.E. Breck, S.M. Bartell, and J.F. Kitchell. 1982. Evaluating the constraints of temperature, activity and consumption on growth of largemouth bass. Environ. Biol. Fishes 9:263-275.

Ricker, W.E. 1946. Production and utilization of fish populations. Ecological Monographs 16:373-391.

Rieman, B.E., R.C. Beamesderfer, S. Vigg, and T.P. Poe. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia reservoir Part IV: Estimated total loss and mortality of juvenile salmonids to northern squawfish, walleye, and smallmouth bass. Pages 249-273 *in* T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Steigenberger, L.W., and P.A. Larkin. 1974. Feeding activity and rates of digestion of northern squawfish (*Ptychocheilus oregonensis*). J. Fish. Res. Board Can. 31:411-420.

Stewart, D.J. and F.P. Binkowski. 1986. Dynamics of consumption and food conversion by Lake Michigan alewives: an energetics-modeling synthesis. Trans. Am. Fish. Soc. 115:643-661.

Thompson, R.B. 1959. Food of the squawfish *Ptychocheilus oregonensis* (Richardson) of the lower Columbia River. U.S. Fish and Wildlife Service, Fishery Bulletin 158:43-58.

Thornton, K.W., and A.S. Lessem. 1978. A temperature algorithm for modifying biological rates. Trans. Am. Fish. Soc. 107:284-287.

Vigg, S. 1988. Functional response of northern squawfish predation to salmonid prey density in McNary Tailrace, Columbia River. Pages 175-207 *in* T.P. Poe and B.E. Rieman, editors. Resident fish predation on juvenile salmonids in John Day Reservoir, 1983-1986. Final Report (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) to Bonneville Power Administration, Portland, Oregon.

Vigg, S., T.P. Poe, L.A. Prendergast, and H.C. Hansel. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia River reservoir: Part II. Consumption rates of northern squawfish, walleye, smallmouth bass, and channel catfish. Pages 56-115 in T.P. Poe and B.E. Rieman, editors. Resident fish predation on juvenile salmonids in John Day Reservoir, 1983-1986. Final Report (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) to Bonneville Power Administration, Portland, Oregon.

Wootton, R.J., J.R.M. Allen, and S.J. Cole. 1980. Effect of body weight and temperature on the maximum daily food consumption of *Gasterosteus aculeatus* L. and *Phoxinus phoxinus* (L.): selecting an appropriate model. J. Fish Biol. 17:695-705.

APPENDIX A-7. Biological data from bottom gill net sampling in John Day Reservoir, 1989. The total number of net sets was 165, including 159 standardized (1 to 3 hour) sets for catch per unit effort analyses. Location codes are: 159xxx = John Day Forebay; 156xxx = Arlington; 163xxx = Irrigon; 151xxx= Paterson: 161xxx = McNary Tailrace. Species codes are: SQF = northern squawfish; WAL = walleye. Blanks indicate zero catch, and dashed lined indicate missing data.

Standard bottom sill net sets with time intervals of 1-3 hours:

| NET SET NUNBER | DATE (mddyy) | LOCATION | START TIME | STOP TIM | EFFORT (hours) | MN (depth m) | MAX (depth m) | SPECIES | COLLECTION NUNBER | BAR NESH (cm) | LENGTH (mm) | WEIGHT (g) | SEX | GONAD WEIGHT (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 52289 | 161053 | 1030 | 1300 | 2.5 | 1.5 | 3.0 | SQF | 1 | 4.4 | 352 | 650 | F | --- |
| 1 | 52289 | 161053 | 1030 | 1300 | 2.5 | 1.5 | 3.0 | SQF | 2 | 4.4 | 481 | 1640 | F | --- |
| 2 | 52289 | 161131 | 1200 | 1350 | 1.8 | 3.0 | 5.5 | | | | | | | |
| 3 | 52589 | 161053 | 510 | 710 | 2.0 | 1.5 | 6.1 | | | | | | | |
| 4 | 52589 | 161140 | 610 | 810 | 2.0 | 2.4 | 6.1 | SQF | 3 | 3.2 | 364 | 620 | M | --- |
| 5 | 53189 | 163120 | 1050 | 1250 | 2.0 | 3.0 | 16.8 | | | | | | | |
| 6 | 53189 | 151043 | 1130 | 1330 | 2.0 | 1.5 | 4.0 | SQF | 4 | 4.4 | 397 | 1050 | F | --- |
| 7 | 53189 | 163010 | 1400 | 1545 | 1.8 | 3.0 | 7.6 | SQF | 5 | 3.2 | 349 | 660 | M | --- |
| 8 | 53189 | 151050 | 1430 | 1600 | 1.5 | 6.1 | 10.7 | | | | | | | |
| 9 | 60189 | 163110 | 710 | 930 | 2.3 | 6.7 | 6.7 | | | | | | | |
| 10 | 60189 | 151070 | 820 | 1020 | 2.0 | 2.1 | 3.7 | | | | | | | |
| 11 | 60189 | 163100 | 935 | 1235 | 3.0 | 3.0 | 6.1 | | | | | | | |
| 12 | 60289 | 163080 | 620 | 820 | 2.0 | 10.7 | 12.2 | | | | | | | |
| 13 | 60289 | 151050 | 720 | 920 | 2.0 | 6.1 | 13.7 | | | | | | | |
| 14 | 60289 | 151043 | 840 | 1010 | 1.5 | 2.1 | 5.2 | | | | | | | |
| 15 | 60589 | 156020 | 1300 | 1500 | 2.0 | 7.6 | 13.7 | | | | | | | |
| 16 | 60689 | 156020 | 1310 | 1510 | 2.0 | 9.1 | 21.3 | | | | | | | |
| 17 | 60689 | 156020 | 1320 | 1520 | 2.0 | 12.2 | 21.3 | SQF | 15 | 3.2 | 309 | 358 | F | 13.00 |
| 18 | 60689 | 156130 | 1540 | 1800 | 2.3 | 6.1 | 21.3 | | | | | | | |
| 19 | 60689 | 156130 | 1550 | '1740 | 1.8 | 12.2 | 18.3 | | | | | | | |
| 20 | 60789 | 156150 | 1100 | 1300 | 2.0 | 6.1 | 9.1 | | | | | | | |
| 21 | 60789 | 156060 | 1400 | 1600 | 2.0 | 4.6 | 9.1 | | | | | | | |
| 22 | 60889 | 156130 | 530 | 730 | 2.0 | 12.2 | 22.9 | SQF | 16 | 4.6 | 356 | 619 | F | 25.80 |
| 23 | 60889 | 156130 | 740 | 940 | 2.0 | 10.7 | 18.3 | | | | | | | |
| 26 | 61389 | 159094 | 1700 | 1900 | 2.0 | 9.1 | 18.3 | | | | | | | |
| 25 | 61389 | 159094 | 1710 | 1910 | 2.0 | 3.0 | 21.3 | | | | | | | |
| 26 | 61389 | 159094 | 1905 | 2050 | 1.8 | 6.1 | 12.2 | | | | | | | |
| 27 | 61389 | 159095 | 1915 | 2105 | 1.8 | 3.0 | 25.9 | | | | | | | |
| 28 | '61489 | 159081 | 845 | 1045 | 2.0 | 3.0 | 22.9 | SQF | 17 | 3.2 | 319 | 479 | U | --- |
| 28 | 61489 | 159081 | 845 | 1045 | 2.0 | 3.0 | 22.9 | SQF | 18 | 3.2 | 278 | 304 | U | --- |
| 28 | 61489 | 159081 | 865 | 1045 | 2.0 | 3.0 | 22.9 | SQF | 19 | 3.2 | 272 | 268 | U | --- |
| 28 | 61489 | 159081 | 815 | 1045 | 2.0 | 3.0 | 22.9 | SQF | 20 | 3.2 | 285 | 342 | U | --- |
| 28 | 61489 | 159081 | 845 | 1045 | 2.0 | 3.0 | 22.9 | SQF | 21 | 3.2 | 275 | 265 | U | --- |
| 29 | 61489 | 159080 | 930 | 1230 | 3.0 | 6.1 | 15.2 | SQF | 22 | 3.2 | 301 | 384 | U | --- |
| 29 | 61689 | 159080 | 930 | 1230 | 3.0 | 6.1 | 15.2 | SQF | 23 | 3.2 | 289 | 314 | U | --- |
| 30 | 61489 | 159081 | 1105 | 1305 | 2.0 | 7.6 | 18.3 | SQF | 26 | 1.4 | 393 | 823 | U | --- |
| 31 | 61489 | 159092 | 1420 | 1615 | 1.9 | 9.1 | 22.9 | | | | | | | |
| 32 | 61489 | 159110 | 1430 | 1630 | 2.0 | 9.1 | 15.2 | | | | | | | |
| 33 | 61589 | 159060 | 815 | 1065 | 2.0 | 9.1 | 22.9 | | | | | | | |
| 34 | 61589 | 159060 | 850 | 1105 | 2.3 | 4.6 | 19.8 | | | | | | | |
| 35 | 61589 | 159060 | 1115 | 1315 | 2.0 | 13.7 | 27.4 | | | | | | | |
| 36 | 61589 | 159050 | 1125 | 1326 | 1.9 | 9.1 | 12.2 | | | | | | | |
| 37 | 61989 | 161072 | 1040 | 1240 | 2.0 | 3.0 | 6.1 | WAL | 25 | 3.2 | 416 | 827 | U | --- |
| 38 | 61989 | 161080 | 1100 | 1300 | 2.0 | 7.6 | 10.7 | | | | | | | |
| 39 | 61989 | 161072 | 1245 | 1445 | 2.0 | 1.5 | b.6 | SQF | 26 | --- | 304 | 369 | U | --- |
| 40 | 61989 | 161061 | 1315 | 1515 | 2.0 | 6.1 | 13.7 | SQF | 27 | 4.4 | 302 | 310 | M | --- |
| 41 | 62089 | 161030 | 845 | 1045 | 2.0 | 3.0 | 12.2 | SQF | 28 | --- | 364 | 539 | F | --- |
| 41 | 62089 | 161030 | 845 | 1045 | 2.0 | 3.0 | 12.2 | SQF | 29 | --- | 324 | 391 | U | --- |
| 42 | 62089 | 161030 | 855 | 1055 | 2.0 | 4.6 | 10.7 | | | | | | | |
| 43 | 62089 | 161050 | 1105 | 1305 | 2.0 | 2.1 | 4.6 | SQF | 31 | 1.1 | 304 | 363 | U | --- |
| 44 | 62089 | 161050 | 1115 | 1315 | 2.0 | 1.8 | 3.7 | SQF | 30 | 3.2 | 295 | 351 | U | --- |
| 45 | 62189 | 161072 | 830 | 1030 | 2.0 | 2.1 | 5.2 | SQF | 32 | 1.4 | 346 | 593 | F | --- |

| NET SET NUMBER | OATE (mddyy) | LOCATION | START TIME | STOP TINE | EFFORT (hours) | MIN (depth m) | MAX (depth m) | SPECIES | COLLECTION NUMBER | BAR Mesh (cm) | LENGTH (mm) | WEIGHT (g) | SEX | GONAD WEIGHT (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 46 | 62189 | 161072 | 840 | 1040 | 2.0 | 1.5 | 4.6 | SQF | 33 | 4.4 | 402 | 751 | F | 93.4 |
| 47 | 62189 | 161030 | 1125 | 1340 | 2.3 | 7.6 | 10.7 | WAL | 34 | 1.4 | 417 | 361 | U | --- |
| 47 | 62189 | 161030 | 1125 | 1340 | 2.3 | 7.6 | 10.7 | SQF | 35 | 4.4 | 358 | 664 | F | 86.0 |
| 48 | 62189 | 161030 | 1135 | 1405 | 2.5 | 4.6 | 7.6 | SQF | 36 | 4.4 | 309 | 357 | M | 20.7 |
| 19 | 62689 | 163060 | 815 | 1015 | 2.0 | 3.0 | 15.2 | | | | | | | |
| 50 | 62689 | 163060 | 825 | 1025 | 2.0 | 4.6 | 15.2 | | | | | | | |
| 51 | 62789 | 151070 | 810 | 1010 | 2.0 | 3.0 | 1.6 | | | | | | | |
| 52 | 62789 | 151080 | 820 | 1025 | 2.1 | 12.2 | 12.2 | | | | | | | |
| 53 | 62789 | 151060 | 1115 | 1315 | 2.0 | 3.0 | 9.1 | | | | | | | |
| 54 | 62789 | 151060 | 1125 | 1330 | 2.1 | 6.1 | 12.2 | | | | | | | |
| 55 | 62889 | 163032 | 805 | 1005 | 2.0 | 3.0 | 9.1 | | | | | | | |
| 56 | 62889 | 163031 | 815 | 1015 | 2.0 | 3.0 | 7.6 | | | | | | | |
| 57 | 70589 | 156160 | 1025 | 1225 | 2.0 | 6.6 | 7.6 | | | | | | | |
| 58 | 70589 | 156140 | 1030 | 1230 | 2.0 | 7.6 | 10.7 | | | | | | | |
| 59 | 70589 | 156150 | 1235 | 1440 | 2.1 | 3.0 | 6.1 | | | | | | | |
| 60 | 70589 | 156150 | 1240 | 1445 | 2.3 | 6.1 | 9.1 | | | | | | | |
| 61 | 70689 | 156130 | 155 | 655 | 2.0 | 7.6 | 21.3 | SQF | 72 | 5.1 | 365 | 516 | F | --- |
| 61 | 70689 | 156130 | 155 | 655 | 2.0 | 7.6 | 21.3 | SQF | 73 | 3.2 | 315 | 358 | F | 25.6 |
| 61 | 70689 | 156130 | A55 | 655 | 2.0 | 7.6 | 21.3 | SQF | 74 | 6.4 | 340 | 449 | F | --- |
| 62 | 70689 | 156130 | 500 | 710 | 2.2 | 6.1 | 18.3 | WAL | 75 | --- | 399 | 726 | U | --- |
| 62 | 70689 | 156130 | 500 | 710 | 2.2 | 6.1 | 18.3 | SQF | 76 | --- | 276 | 260 | F | --- |
| 62 | 70689 | 156130 | 500 | 710 | 2.2 | 6.1 | 18.3 | SQF | 77 | --- | 298 | 282 | F | --- |
| 63 | 70689 | 156020 | 715 | 950 | 2.1 | 3.0 | 9.1 | | | | | | | |
| 61 | 70689 | 156020 | 750 | 1000 | 2.2 | 7.6 | 18.3 | SQF | 78 | --- | 292 | 290 | M | 7.9 |
| 65 | 70689 | 156020 | 1010 | 1210 | 2.0 | 6.1 | 13.7 | SQF | 79 | 3.2 | 286 | 265 | F | --- |
| 66 | 70689 | 156010 | 1015 | 1215 | 2.0 | 6.1 | 26.4 | | | | | | | |
| 67 | 70789 | 156051 | 510 | 710 | 2.0 | 6.1 | 9.1 | | | | | | | |
| 68 | 70789 | 156050 | 515 | 720 | 2.0 | 6.1 | 12.2 | SQF | 80 | 5.1 | 427 | 1325 | F | 75.0 |
| 69 | 70789 | 156080 | 740 | 940 | 2.0 | 9.1 | 15.2 | | | | | | | |
| 70 | 70789 | 156080 | 750 | 950 | 2.0 | 3.0 | 3.0 | SGF | 84 | --- | 296 | --- | F | 31.1 |
| 71 | 71389 | 159040 | 905 | 1105 | 2.0 | 6.1 | 12.2 | | | | | | | |
| 72 | 71389 | 159010 | 915 | 1115 | 2.0 | 7.6 | 18.3 | SQF | 86 | --- | 389 | 633 | F | --- |
| 72 | 71389 | 159010 | 915 | 1115 | 2.0 | 7.6 | 18.3 | SQF | a7 | --- | 355 | 631 | F | --- |
| 72 | 71389 | 159040 | 915 | 1115 | 2.0 | 7.6 | 18.3 | SQF | 88 | --- | 276 | 289 | F | --- |
| 72 | 71389 | 159010 | 915 | 1115 | 2.0 | 7.6 | 18.3 | SQF | 89 | --- | 391 | 666 | F | --- |
| 73 | 71389 | 159050 | 925 | 1125 | 2.0 | 6.1 | 27.4 | | | | | | | |
| 74 | 71389 | 159050 | 935 | 1135 | 2.0 | 3.0 | 9.1 | | | | | | | |
| 75 | 71389 | 159013 | 1110 | 1360 | 2.0 | 6.1 | 16.8 | | | | | | | |
| 76 | 71389 | 159013 | 1155 | 1355 | 2.0 | 6.1 | 22.9 | | | | | | | |
| 77 | 71389 | 159060 | 1205 | 1105 | 2.0 | 7.6 | 12.2 | SQF | 90 | 1.1 | 341 | 485 | F | --- |
| 78 | 71389 | 159063 | 1150 | 1350 | 2.0 | 6.1 | 18.3 | SQF | 91 | 3.2 | 264 | 215 | II | --- |
| 79 | 71189 | 159080 | 500 | 705 | 2.1 | 6.1 | 27.1 | SQF | 92 | 3.2 | 306 | 329 | F | --- |
| 80 | 71489 | 159080 | 505 | 715 | 2.2 | 6.1 | 27.1 | SQF | 93 | 3.2 | 375 | 590 | F | --- |
| 80 | 71489 | 159080 | 505 | 715 | 2.2 | 6.1 | 27.1 | SQF | 94 | 3.2 | 300 | 276 | M | --- |
| 81 | 71189 | 159080 | 510 | 720 | 2.2 | 6.1 | 21.1 | SQF | 95 | 4.4 | 392 | 821 | F | --- |
| 81 | 71489 | 159080 | 510 | 720 | 2.2 | 6.1 | 24.4 | SQF | 96 | 1.6 | 319 | 366 | M | --- |
| 81 | 71189 | 159080 | 510 | 720 | 2.2 | 6.1 | 24.4 | SQF | 97 | 3.2 | 269 | 241 | M | --- |
| 82 | 71489 | 159080 | 450 | 650 | 2.0 | 6.1, | 21.3 | SQF | 98 | 3.2 | 271 | 231 | M | --- |
| 83 | 71189 | 159090 | 735 | 950 | 2.3 | 6.1 | 25.9 | SQF | 102 | 4.4 | 327 | 404 | F | --- |
| 84 | 71489 | 159090 | 730 | 930 | 2.0 | 6.1 | 24.4 | SQF | 99 | 3.2 | 303 | 324 | F | --- |
| 86 | 71489 | 159090 | 730 | 930 | 2.0 | 6.1 | 24.6 | SQF | 100 | 5.1 | 386 | 717 | F | --- |
| 84 | 71689 | 159090 | 730 | 930 | 2.0 | 6.1 | 21.1 | SQF | 101 | 3.2 | 306 | 325 | M | --- |

| NET SET NUMBER | DATE (mddyy) | LOCATION | START TIME | STOP TINE | EFFORT (hours) | MIN (depth m) | MAX (depth m) | SPECIES | COLLECTION NUMBER | BAR Mesh (cm) | LENGTH (mm) | WEIGHT (g) | SEX | GONAD WEIGHT (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 85 | 71189 | 159090 | 740 | 1014 | 2.5 | 7.6 | 19.8 | | | | | | | |
| 86 | 71189 | 159090 | 750 | 1024 | 2.5 | 7.6 | 27.6 | | | | | | | |
| 87 | 71789 | 161030 | 1810 | 2040 | 2.0 | 3.0 | 1.6 | | | | | | | |
| 88 | 71789 | 161030 | 1815 | 2045 | 2.0 | 1.6 | 6.1 | | | | | | | |
| 89 | 71789 | 161030 | 1850 | 2050 | 2.0 | 7.6 | 9.1 | WAL | 103 | --- | 612 | 826 | U | --- |
| 90 | 71789 | 161030 | 1855 | 2055 | 2.0 | 6.6 | 6.1 | SQF | 104 | --- | 348 | 542 | U | --- |
| 91 | 71989 | 161030 | 330 | 550 | 2.3 | 6.1 | 7.6 | WAL | 132 | --- | 331 | 441 | U | --- |
| 92 | 71989 | 161053 | 315 | 525 | 2.2 | 6.1 | 7.6 | SQF | 133 | --- | 128 | 1111 | F | --- |
| 92 | 71989 | 161053 | 315 | 525 | 2.2 | 6.1 | 7.6 | SQF | 134 | --- | 333 | 503 | F | --- |
| 92 | 71989 | 161053 | 315 | 525 | 2.2 | 6.1 | 7.6 | SQF | 135 | --- | 321 | 431 | F | --- |
| 93 | 71989 | 161030 | 325 | 540 | 2.3 | 6.1 | 9.1 | | | | | | | |
| 94 | 71989 | 161050 | 310 | 515 | 2.1 | 5.2 | 7.0 | SQF | 136 | --- | 378 | 733 | F | --- |
| 91 | 71989 | 161050 | 310 | 515 | 2.1 | 5.2 | 7.0 | SQF | 137 | --- | 279 | 252 | M | --- |
| 94 | 71989 | 161050 | 310 | 515 | 2.1 | 5.2 | 7.0 | SQF | 138 | --- | 113 | 879 | F | --- |
| 94 | 71989 | 161050 | 310 | 515 | 2.1 | 5.2 | 7.0 | SQF | 139 | --- | 312 | 450 | M | --- |
| 95 | 71989 | 161090 | 735 | 915 | 1.7 | 6.1 | 9.1 | | | | | | | |
| 96 | 71989 | 161080 | 720 | 940 | 2.3 | --- | --- | | | | | | | |
| 97 | 71989 | 161080 | 715 | 930 | 2.3 | 4.6 | 6.1 | | | | | | | |
| 98 | 71989 | 161092 | 725 | 955 | 2.4 | 6.1 | 7.6 | | | | | | | |
| 99 | 72489 | 151080 | 1620 | 1820 | 2.0 | 7.6 | 12.2 | | | | | | | |
| 100 | 72189 | 151070 | 1625 | 1825 | 2.0 | 4.6 | 6.1 | | | | | | | |
| 101 | 72189 | 151080 | 1615 | 1900 | 2.8 | 6.1 | 12.2 | SQF | 111 | --- | 438 | 1066 | F | --- |
| 102 | 72189 | 163090 | 1930 | 2130 | 2.0 | 3.0 | 18.3 | SQF | 113 | --- | 129 | 909 | F | --- |
| 103 | 72689 | 163090 | 1940 | 2140 | 2.0 | 3.0 | 18.3 | SQF | 112 | --- | 422 | 907 | F | --- |
| 101 | 72189 | 163120 | 1950 | 2150 | 2.0 | 3.0 | 18.3 | SQF | 144 | --- | 310 | 400 | F | --- |
| 105 | 72189 | 163120 | 2000 | 2200 | 2.0 | 7.6 | 18.3 | | | | | | | |
| 106 | 72589 | 163101 | 1630 | 1830 | 2.0 | 4.6 | 9.1 | | | | | | | |
| 107 | 72589 | 163101 | 1640 | 1840 | 2.0 | 6.1 | 9.1 | | | | | | | |
| 108 | 72589 | 163101 | 1650 | 1850 | 2.0 | 6.1 | 7.6 | | | | | | | |
| 109 | 72589 | 163101 | 1700 | 1900 | 2.0 | 6.1 | 7.6 | | | | | | | |
| 110 | 72589 | 163090 | 1910 | 2110 | 2.0 | 3.0 | 6.1 | | | | | | | |
| 111 | 72589 | 163090 | 1925 | 2125 | 2.0 | 3.0 | 9.1 | SQF | 115 | --- | 285 | 260 | F | --- |
| 112 | 72589 | 163060 | 1940 | 2140 | 2.0 | 3.0 | 12.2 | SQF | lb6 | --- | 301 | 371 | F | --- |
| 113 | 72589 | 163060 | 1950 | 2150 | 2.0 | 3.0 | 15.2 | | | | | | | |
| 114 | 72689 | 161020 | 715 | 1045 | 3.0 | 13.7 | 18.3 | SQF | lb7 | --- | 331 | 487 | F | --- |
| 115 | 72889 | 163010 | 515 | 715 | 2.0 | 1.6 | 6.1 | | | | | | | |
| 116 | 72889 | 163010 | 525 | 725 | 2.0 | 3.0 | 7.6 | | | | | | | |
| 117 | 72889 | 163010 | 530 | 730 | 2.0 | 4.6 | 10.7 | | | | | | | |
| 118 | 72889 | 163010 | 540 | 740 | 2.0 | 1.5 | 9.1 | | | | | | | |
| 119 | 72889 | 163060 | 715 | 945 | 2.0 | 6.6 | 15.2 | | | | | | | |
| 120 | 72889 | 163060 | 755 | 955 | 2.0 | 4.6 | 13.7 | | | | | | | |
| 121 | 72889 | 163060 | 805 | 1005 | 2.0 | 6.1 | 12.2 | | | | | | | |
| 122 | 72889 | 163060 | 810 | 1010 | 2.0 | 6.1 | 10.7 | | | | | | | |
| 123 | 73189 | 156130 | 1500 | 1700 | 2.0 | 7.6 | 2b.b | | | | | | | |
| 124 | 73189 | 156130 | 1510 | 1710 | 2.0 | 9.1 | 21.3 | | | | | | | |
| 125 | 73189 | 156130 | 1520 | 1720 | 2.0 | 10.7 | 18.3 | | | | | | | |
| 126 | 73189 | 156010 | 1750 | 1950 | 2.0 | 7.6 | 12.2 | | | | | | | |
| 127 | 73189 | 156130 | 1530 | 1730 | 2.0 | 10.7 | 19.8 | SQF | 150 | --- | 387 | 643 | U | --- |
| 128 | 73189 | 156010 | 1805 | 2005 | 2.0 | 9.1 | 12.2 | | | | | | | |
| 129 | 80189 | 156130 | 610 | 810 | 2.0 | 9.1 | 27.4 | | | | | | | |
| 130 | 80189 | 156130 | 620 | 820 | 2.0 | 9.1 | 21.3 | | | | | | | |
| 131 | 80189 | 156130 | 630 | 840 | 2.2 | 12.2 | 18.3 | SQF | 148 | --- | 301 | 261 | U | --- |

| NET SET NUMBER | DATE (mddyy) | LOCATION | START TIME | STOP TIME | EFFORT (hours) | MIN (depth m) | MAX (depth m) | SPECIES | COLLECTION NUMBER | BAR Mesh (cm) | LENGTH (mm) | WEIGH1 (g) | SEX | GONAO WEIGHT (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 132 | 80189 | 156130 | 640 | 840 | 2.0 | 12.2 | 19.8 | SQF | lb9 | --- | 370 | 699 | U | --- |
| 133 | 80289 | 161050 | 410 | 610 | 2.0 | 3.0 | 7.6 | WAL | 151 | --- | 117 | 893 | U | --- |
| 134 | 80289 | 161050 | 420 | 620 | 2.0 | 3.4 | 1.6 | SQF | 152 | --- | 351 | 551 | U | --- |
| 134 | 80289 | 161050 | 420 | 620 | 2.0 | 3.0 | 1.6 | SQF | 153 | --- | 383 | 712 | U | --- |
| 134 | 80289 | 161050 | 420 | 620 | 2.0 | 3.0 | 1.6 | SQF | 154 | --- | 433 | 972 | U | --- |
| 134 | 80289 | 161050 | 420 | 620 | 2.0 | 3.0 | 1.6 | SQF | 155 | --- | 334 | 508 | U | --- |
| 134 | 80289 | 161050 | 420 | 620 | 2.0 | 3.0 | 4.6 | SQF | 156 | --- | 359 | 492 | U | --- |
| 135 | 80289 | 161053 | 430 | 630 | 2.0 | 4.6 | 7.6 | SQF | 157 | --- | 374 | 61h | U | --- |
| 136 | 80289 | 161050 | 440 | 640 | 2.0 | 3.0 | 6.1 | | | | | | | |
| 137 | 80289 | 161030 | 715 | 915 | 2.0 | 1.5 | 6.1 | | | | | | | |
| 138 | 80289 | 161030 | 725 | 925 | 2.0 | 4.6 | 7.6 | | | | | | | |
| 139 | 80289 | 161030 | 735 | 935 | 2.0 | 4.6 | 7.6 | | | | | | | |
| 140 | 80289 | 161030 | 745 | 945 | 2.0 | 6.1 | 6.1 | | | | | | | |
| 141 | 80789 | 159060 | 1600 | 1800 | 2.0 | 6.1 | 21.3 | | | | | | | |
| lb2 | 80789 | 159060 | 1610 | 1810 | 2.0 | 9.1 | 27.4 | SQF | 158 | 5.1 | 499 | 1323 | F | --- |
| lb2 | 80789 | 159060 | 1610 | 1810 | 2.0 | 9.1 | 27.4 | SQF | 159 | 3.2 | 327 | 406 | F | --- |
| 143 | 80789 | 159060 | 1620 | 1825 | 2.1 | 9.1 | 22.9 | | | | | | | |
| lb6 | 80789 | 159060 | 1630 | 1830 | 2.0 | 9.1 | 19.8 | | | | | | | |
| lb5 | 80789 | 159080 | 1850 | 2050 | 2.0 | 9.1 | 18.3 | | | | | | | |
| lb6 | 80789 | 159080 | 1900 | 2100 | 2.0 | 9.1 | 15.2 | | | | | | | |
| 147 | 80789 | 159080 | 1910 | 2110 | 2.0 | 12.2 | 24.4 | SQF | 160 | 4.4 | 384 | 603 | F | --- |
| lb8 | 80889 | 159091 | 400 | 600 | 2.0 | 6.1 | 21.3 | SQF | 161 | 4.4 | 378 | 689 | F | --- |
| lb9 | 80889 | 159091 | 410 | 610 | 2.0 | 6.1 | 21.3 | SQF | 162 | 4.4 | 363 | 582 | F | --- |
| 119 | 80889 | 159091 | 410 | 610 | 2.0 | 6.1 | 21.3 | SQF | 163 | 3.2 | 276 | 223 | M | --- |
| 149 | 80889 | 159091 | 410 | 610 | 2.0 | 6.1 | 21.3 | SQF | 164 | 5.1 | 442 | 1130 | F | --- |
| 150 | 80889 | 159080 | 420 | 620 | 2.0 | --- | --- | SQF | --- | --- | --- | --- | --- | --- |
| 151 | 80889 | 159080 | 430 | 630 | 2.0 | 6.1 | 21.3 | SQF | 165 | 4.4 | 388 | 719 | F | --- |
| 151 | 80889 | 159080 | 130 | 630 | 2.0 | 6.1 | 21.3 | SQF | 166 | 5.1 | 119 | 865 | F | --- |
| 151 | 80889 | 159080 | 130 | 630 | 2.0 | 6.1 | 21.3 | SQF | 167 | 4.1 | 354 | 521 | M | --- |
| 152 | 80889 | 159130 | 1520 | 1720 | 2.0 | 9.1 | 21.3 | | | | | | | |
| 153 | 80889 | 159130 | 1530 | 1730 | 2.0 | 12.2 | 22.9 | | | | | | | |
| 154 | 80889 | 159130 | 1510 | 1710 | 2.0 | 7.6 | 22.9 | | | | | | | |
| 155 | 80889 | 159130 | 1550 | 1750 | 2.0 | 13.7 | 24.4 | | | | | | | |
| 156 | 80889 | 159110 | 1800 | 2000 | 2.0 | 6.1 | 18.3 | | | | | | | |
| 157 | 80889 | 159110 | 1810 | 2010 | 2.0 | 6.1 | 21.3 | | | | | | | |
| 158 | 80889 | 159110 | 1820 | 2020 | 2.0 | 9.1 | 22.9 | SQF | 168 | 3.2 | 306 | 386 | F | --- |
| 158 | 80889 | 159110 | 1820 | 2020 | 2.0 | 9.1 | 22.9 | SQF | 169 | 3.2 | 293 | 298 | II | --- |
| 159 | 80889 | 159110 | 1830 | 2030 | 2.0 | 9.1 | 22.9 | SQF | 170 | 4.4 | 404 | 693 | F | --- |

Non-standard bottom gill net sets with time intervals other than 1-3 hours:

| NET SET NUMBER | LOCATION | START DATE | START TINE | STOP DATE | STOP DATE | EFFORT (hours) | MN (depth m) | NAX (depth m) | SPECIES | COLLECTION NUMBER | EAR MESH (cm) | LENGTH (mm) | WEIGHT (g) | SEX | GONAD WEIGHT (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 160 | 156130 | 60589 | 740 | 64689 | 915 | 25.1 | 6.1 | 22.9 | SQF | 6 | 5.1 | 396 | 940 | F | 43.1 |
| 160 | 156130 | 60589 | 760 | 60689 | 915 | 25.6 | 6.1 | 22.9 | SQF | 7 | 4.4 | 362 | 620 | F | 56.7 |
| 160 | 156130 | 60589 | 740 | 60689 | 915 | 25.1 | 6.1 | 22.9 | SQF | 8 | 6.1 | 271 | 310 | F | --- |
| 160 | 156130 | 60589 | 740 | 60689 | 915 | 25.4 | 6.1 | 22.9 | SQF | 9 | 1.4 | 277 | 300 | F | --- |
| 160 | 156130 | 60589 | 740 | 60689 | 915 | 25.4 | 6.1 | 22.9 | SQF | 10 | 3.2 | 312 | 400 | F | --- |
| 160 | 156130 | 60589 | 760 | 60689 | 915 | 25.6 | 6.1 | 22.9 | SQF | 11 | 3.2 | 269 | 310 | F | --- |
| 160 | 156130 | 60589 | 740 | 60689 | 915 | 25.6 | 6.1 | 22.9 | SQF | 12 | 3.2 | 254 | 250 | F | --- |
| 160 | 156130 | 60589 | 740 | 60689 | 915 | 25.6 | 6.1 | 22.9 | SQF | 13 | 3.2 | 271 | 300 | U | --- |
| 160 | 156130 | 60589 | 740 | 60689 | 915 | 25.6 | 6.1 | 22.9 | SQF | 16 | 3.2 | 283 | 310 | U | --- |
| 161 | 161050 | 71789 | 2110 | 71889 | 910 | 12 | 6.6 | 6.1 | SQF | 115 | --- | 364 | 695 | F | --- |
| 161 | 161050 | 71789 | 2110 | 71889 | 910 | 12 | 1.6 | 6.1 | SQF | 116 | --- | 355 | 529 | F | --- |
| 161 | 161050 | 71789 | 2110 | 71889 | 910 | 12 | 1.6 | 6.1 | SQF | 117 | --- | 323 | 416 | F | --- |
| 161 | 161050 | 71789 | 2110 | 71889 | 910 | 12 | 4.6 | 6.1 | SQF | 118 | --- | 460 | 1270 | F | --- |
| 161 | 161050 | 71789 | 2110 | 71889 | 910 | 12 | b.6 | 6.1 | SQF | 119 | --- | 681 | 1301 | F | --- |
| 161 | 161050 | 71789 | 2110 | 71889 | 910 | 12 | 4.6 | 6.1 | SQF | 120 | --- | 366 | 766 | F | --- |
| 161 | 161050 | 71789 | 2110 | 71889 | 910 | 12 | 6.6 | 6.1 | SQF | 121 | --- | 361 | 622 | F | --- |
| 161 | 161050 | 71789 | 2110 | 71889 | 910 | 12 | 4.6 | 6.1 | SQF | 122 | --- | 335 | 445 | F | --- |
| 162 | 161053 | 71789 | 2115 | 71889 | 945 | 12.5 | 4.6 | 6.1 | SQF | 105 | --- | 355 | 560 | F | --- |
| 162 | 161053 | 71789 | 2115 | 71889 | 915 | 12.5 | 6.6 | 6.1 | SQF | 106 | --- | 309 | 337 | F | --- |
| 162 | 161053 | 71189 | 2115 | 71889 | 965 | 12.5 | 1.6 | 6.1 | SQF | 107 | --- | 335 | 509 | F | --- |
| 162 | 161053 | 71789 | 2115 | 71889 | 945 | 12.5 | 6.6 | 6.1 | SQF | 108 | --- | 677 | 1305 | F | --- |
| 162 | 161053 | 71789 | 2115 | 71889 | 915 | 12.5 | 6.6 | 6.1 | SQF | 109 | --- | 311 | 572 | F | --- |
| 162 | 161053 | 71789 | 2115 | 71889 | 965 | 12.5 | 6.6 | 6.1 | SQF | 110 | --- | 622 | 898 | F | --- |
| 162 | 161053 | 71789 | 2115 | 71889 | 945 | 12.5 | 6.6 | 6.1 | SQF | 111 | --- | 287 | 289 | M | --- |
| 162 | 161053 | 71789 | 2115 | 71889 | 965 | 12.5 | 1.6 | 6.1 | SQF | 112 | --- | 668 | 1020 | F | --- |
| 162 | 161053 | 71789 | 2115 | 71889 | 945 | 12.5 | 6.6 | 6.1 | SQF | 113 | --- | 389 | 732 | M | --- |
| 162 | 161053 | 71789 | 2115 | 71889 | 965 | 12.5 | 6.6 | 6.1 | WAL | 116 | --- | 639 | 1066 | U | --- |
| 163 | 161130 | 71789 | 2125 | 71889 | 1010 | 12.75 | 6.6 | 6.1 | WAL | 126 | --- | 386 | 789 | U | --- |
| 163 | 161130 | 71789 | 2125 | 71889 | 1010 | 12.75 | 6.6 | 6.1 | WAL | 127 | --- | 606 | 931 | U | --- |
| 163 | 161130 | 71789 | 2125 | 71889 | 1010 | 12.75 | 6.6 | 6.1 | WAL | 128 | --- | 625 | 867 | U | --- |
| 163 | 161130 | 71789 | 2125 | 71889 | 1010 | 12.75 | 6.6 | 6.1 | WAL | 129 | --- | 378 | 649 | U | --- |
| 163 | 161130 | 71789 | 2125 | 71889 | 1010 | 12.75 | 6.6 | 6.1 | WAL | 130 | --- | 373 | 636 | U | --- |
| 163 | 161130 | 71789 | 2125 | 71889 | 1010 | 12.75 | 6.6 | 6.1 | WAL | 131 | --- | 567 | 3350 | U | --- |
| 161 | 161130 | 71789 | 2130 | 71889 | 1030 | 13 | 6.6 | 6.1 | SQF | 123 | --- | 331 | 146 | F | --- |
| 164 | 161130 | 71789 | 2130 | 71889 | 1030 | 13 | 6.6 | 6.1 | SQF | 126 | --- | 311 | 380 | F | --- |
| 164 | 161130 | 71789 | 2130 | 71889 | 1030 | 13 | 6.6 | 6.1 | WAL | 125 | --- | 399 | 866 | U | --- |
| 165 | 151080 | 72689 | 1635 | 72689 | 1650 | .25 | 9.1 | 12.2 | SQF | 160 | --- | 365 | 574 | F | --- |

APPENDIX A-8. Preliminary predator control fishery development and evaluation plan.

## DEVELOPMENT OF A SYSTEM-WIDE PREDATOR CONTROL PROGRAN: STEPWISE IMPLEMENTATION OF A PREDATION INDEX , PREDATOR CONTROL FISHERIES, AND EVALUATION PLAN IN THE COLUMBIA RIVER BASIN

Relationship to the Columbia River Basin Fish and Wildlife Program

Mortality of juvenile salmon and steelhead migrating downstream through the Columbia River System* is a major concern of the Columbia Basin Fish and Wildlife Program (NPPC 1987). As outlined in the program, reservoir mortality is an area of emphasis for Bonneville Power Administration funding (NPPC 1987, Section 206 (b)(1)(A)) . Predation is an important component of mortality of juvenile salmonids migrating through the Columbia River System, and northern squawfish (*Ptychocheilus oregonensis*) is an important predator (NPPC 1987, Section 401). There is general agreement that downstream passage and survival of juvenile salmonids are adversely affected by seasonally altered and low flows caused by the hydropower system -- thus increasing their exposure to predators (NPPC 1987, Section 301). The technical work group (TWG) on Reservoir Mortality/Water Budget Effectiveness (NPPC 1987, Section 206(b) (2)) has supported continued research and implementation of control measures to help alleviate the predation problem.

Coordination:

The Oregon Department of Fish and Wildlife (ODFW) and the U.S. Fish and Wildlife Service (USFWS) have been studying predation by northern squawfish on juvenile salmonids in the Columbia River since 1982 (BPA Projects 82-012 and 82-003); coordinated research continues for development of rapid assessment methods to index predation and simulation model* development. In a cooperative feasibility study*, Dr. Susan Hanna, Oregon State University, is evaluating the legal, institutional, socioeconomic, and biological feasibility of using bounty, commercial, and recreational* fisheries to control northern squawfish populations. In a second cooperative agreement, a harvest technology study* being conducted by Dr. Stephen Mathews, University of Washington, Fisheries Research Institute, is focusing on small-boat commercial fisheries -- to determine the combination of fishing methods, reservoir habitats, and time of year that is most efficient in removing northern squawfish from a Columbia River reservoir*, with the least impact on other species. A third cooperative agreement with Dr. L.J. (Sam) Bledsoe, University of Washington, Center for Quantitative Science involves the continued development of simulation modeling as a tool for predator control evaluation. Together these studies help evaluate the general types of fisheries (e.g., commercial, sport, and bounty) and methodology (gear type) that would be most cost-effective and biologically effective in controlling northern squawfish populations.

Implementation of three specific types of fisheries, i.e., subsidized commercial, sport-bounty, and dam angling, are proposed for field testing in

* Underlined terms are defined in the Glossary.

John Day Reservoir in 1990. Since there is an existing small-boat Indian Fishery in Zone 6*, cooperation with Columbia River Inter-Tribal Fish Commission (CRITFC) will facilitate implementation and management of this component. The dam angling component will necessitate close coordination with the U.S. Army Corps of Engineers for access to their projects. Sport-bounty fisheries will be coordinated with ODFW and Washington Department of Wildlife. We are coordinating the contractual development through the Bonneville Power Administration Implementation Planning Process (IPP). Inter-agency technical and policy coordination is provided by the ODFW Columbia River Coordination Section through the Columbia Basin Fish and Wildlife Authority (CBFWA), the Fish Passage Advisory Committee (FPAC), and the Reservoir Mortality / Water Budget Effectiveness Technical Work Group.

Summary of Project:

The Problem: Development of the Columbia River basin hydroelectric system has created impoundments throughout the basin and enabled establishment and enhancement of resident fish that prey on juvenile salmonids as they migrate down-river to the ocean. The hydropower system has exacerbated the problem of predation-related mortality of juvenile salmonids in the Columbia River -- because impoundments have delayed migratory travel time, resulting in prolonged exposure (Raymond 1988). Recent studies (Poe and Rieman, editors 1988) have indicated that predation-caused mortality of juvenile salmonids is significant in John Day Reservoir. Northern squawfish was the most abundant predator (Beamesderfer and Rieman 1988), had high consumption rates on juvenile salmonids (Vigg et *al.* 1988), and accounted for about 80% of the total predation losses in John Day Reservoir (Rieman et al. 1988). On a smaller scale, various studies (Sims et al. 1978; Uremovich et al. 1980) indicate that local concentrations of northern squawfish in tailraces and forebays of Columbia River basin dams can be great. These results are consistent with previous studies in the Columbia River basin that showed northern squawfish to be an important predator of juvenile salmonids (Zimmer 1953; USFWS 1957; Thompson 1959; Thompson and Morgan 1959). Poe et al. (1988) reviewed the literature describing various measures that have been used to control predator populations and identified those measures that had the greatest potential for success in the Columbia River. Modeling simulations of reservoir-wide potential predation in John Day Reservoir indicated that it is not necessary to eradicate northern squawfish in order to substantially reduce predation mortality; but that about 20% exploitation of the squawfish population by a sustained fishery could reduce juvenile salmonid losses to predation about 50% (Rieman and Beamesderfer 1988).

Previous predation research, conducted during 1982-1988, indicated a potential for substantially reducing mortality on juvenile salmonids migrating through Columbia River reservoirs -- by reducing numbers of predaceous northern squawfish (Rieman et al. 1988). Other areas at specific projects have been identified by the Columbia River fisheries community as potential "predation hotspots"* (RM/WBE TWG 5-year plan). Current research (BPA Project 82-012) is conducting an institutional regulatory review pertaining to fishery development: evaluating economics of various types of fisheries; evaluating timing, location and methodology of commercial fishery harvest: and developing a conceptual plan for a step-wise process for the systematic development, conduct, management, and evaluation (incorporating simulation modeling) of commercial, bounty, or sport fisheries on northern squawfish (Hanna 1989; Mathews *et al.* 1989; Bledsoe 1989; Vigg and Burley 1989). An overview of how this research, in conjunction with fishery management community consensus, provides the foundation for predator control implementation (initially as a Test Fishery* in 1990) is presented in Figure 1.

A plan is necessary for the orderly development of commercial, sport, or bounty fisheries on northern squawfish throughout the Columbia River Basin. Decisions must be made to define the scope of the *system-die* Predator Control Program*, and to determine how and where to implement the predator control fisheries starting in 1991 (Figure 2). We are defining "system-wide" as the mainstem Columbia River from Bonneville Dam tailrace to Chief Joseph Dam, and the lower Snake River to Bells Canyon Dam. To proceed with predator control fisheries in a logical and systematic manner, two hypotheses must be tested, i.e., (1) fisheries can effectively exploit northern squawfish populations and thus reduce predation, and (2) predation is a significant source of juvenile salmonid mortality in various reservoirs throughout the Columbia River System. A Test Fishery and Evaluation in John Day Reservoir is designed to address hypothesis (1); and the Predation Index, hypothesis (2).

Development of a plan to evaluate the efficacy of predator control fisheries is essential for scientific management of northern squawfish control fisheries. Implementation of a Test Fishery and Evaluation in 1990 will provide a realistic foundation for a comprehensive Predator Control Program that incorporates evaluation as an integral component. Monitoring northern squawfish populations, and ongoing development of predator-prey modeling will help us to understand the dynamics of predation and predict possible consequences of predator removal.

There is general consensus that predation is a significant problem in John Day Reservoir, but the significance and dynamics of predation are still unknown in other reservoirs in the Columbia River basin. Information is needed to estimate the relative importance of predation by northern squawfish throughout the mid and lower Columbia River and lower Snake River reservoirs, and determine if and where predation control measures should be applied. The cost, time, and uncertainty of absolute predation loss estimates as conducted in John Day Reservoir (Rieman *et al.* 1988) are prohibitive to conduct in each reservoir in the system. If a rapid assessment Predation Index* is determined to be feasible, it will provide a less costly way to determine if the magnitude of fish predation in other Columbia River basin reservoirs is similar to that in John Day Reservoir.

The Goal: The goal of this project is to reduce in-reservoir mortality of juvenile salmonids due to predation by northern squawfish. The primary anticipated benefit is a 50 percent reduction of in-reservoir predation mortality on out-migrating juvenile salmonids. Additional benefits will be to better understand the predator population dynamics affecting salmonid mortality processes, to predict the magnitude of predation mortality under different conditions, and to provide information for fishery managers to evaluate actual success and benefits of the Predator Control Program.

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* Underlined terms are defined in the Glossary.

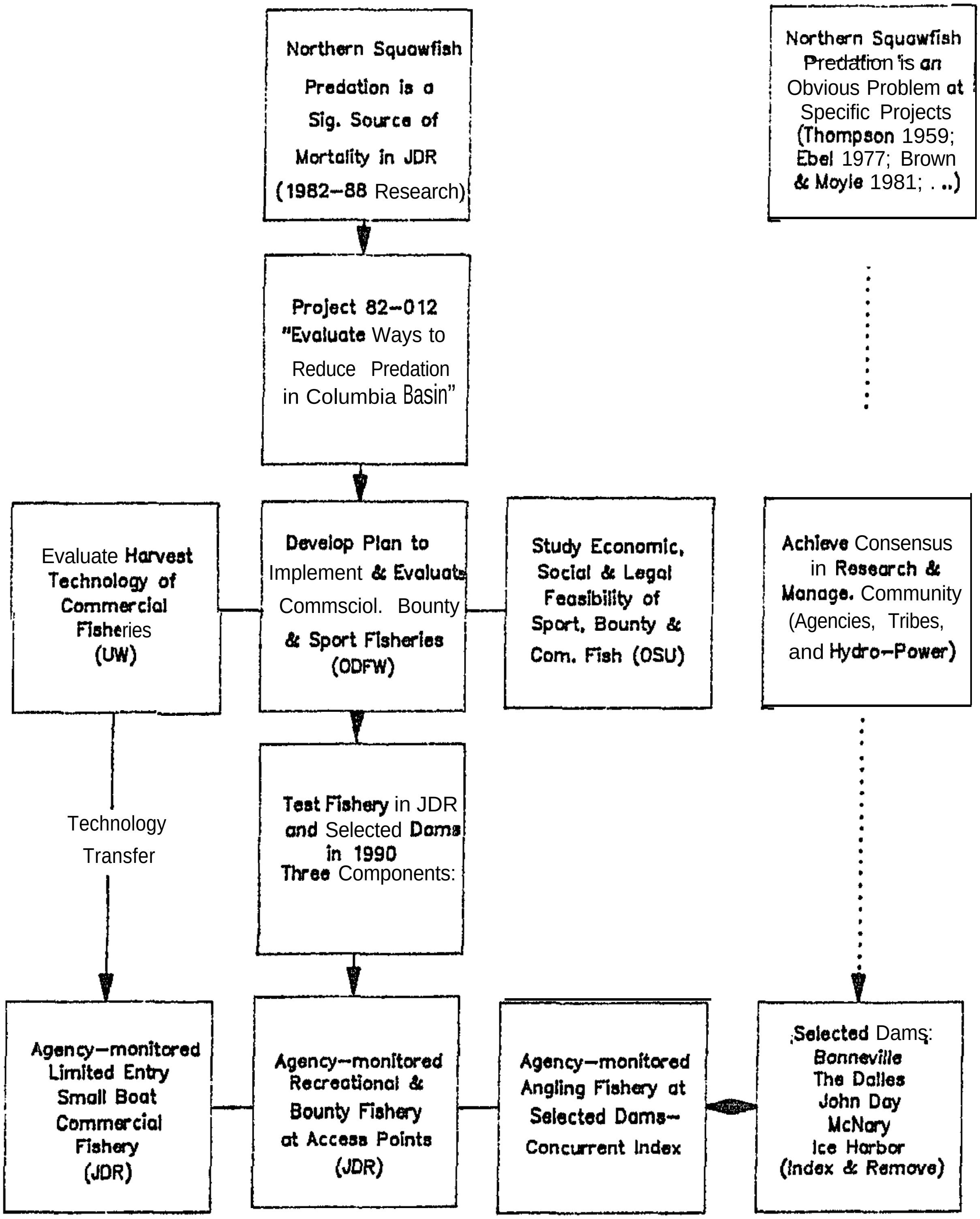


Figure 1. Predator-Prey Project strategy for implementation of small boat commercial and sport-bounty test fisheries in John Day Reservoir: and dam angling removal fisheries and concurrent indexing at project-specific sites in 1990.

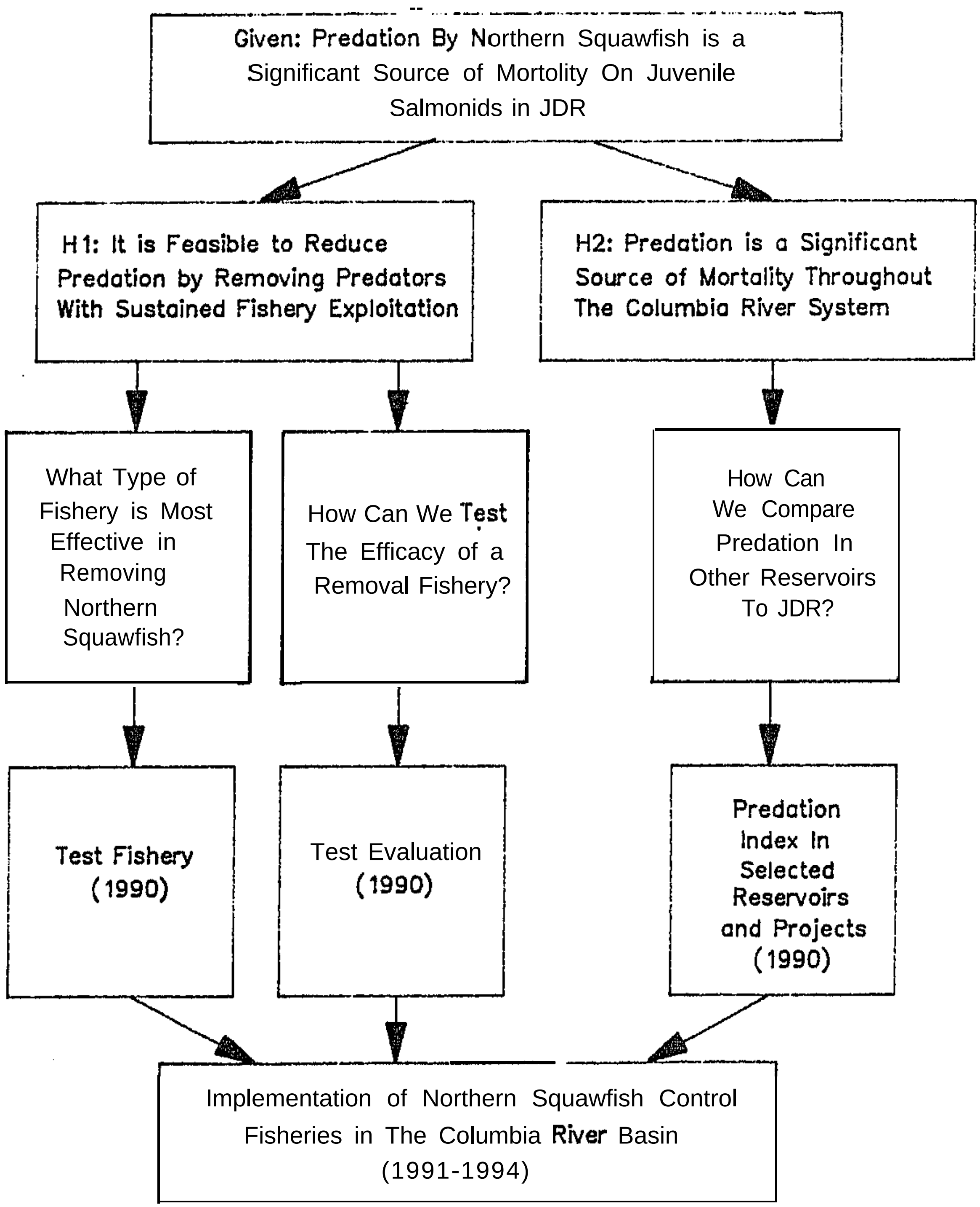


Figure 2. Logic pathway for testing hypotheses necessary for planning system-wide fishery implementation in the Columbia River Basin, beginning in 1991.

**The Objectives:** The overall objectives of this project were defined in the IPP Annual Implementation Work Plan (1989):

1. Determine the significance of predation in Columbia River reservoirs through implementation of indexing of predator abundance and integration with consumption indices.

2. Implement a predator control fishery development plan, beginning with a test fishery in the John Day Reservoir in 1990.

3. Initiate an evaluation of the Predator Control Program.

In order to meet these objectives we have developed the following three research approaches: A. ***Predation Indexing,*** B. ***Test Fishery,*** and C. ***Test Evaluation.***

Approach A: Implementation of a Predation Index to Assess the Relative Magnitude of Predation in Various Columbia River Reservoirs

Concept and Specific Objectives

The ***Predation Index*** will provide a relatively inexpensive way to systematically determine the relative magnitude of fish predation in various reservoirs in the mid and lower Columbia and lower Snake river reservoirs -- compared to concurrent indexing and existing baseline predation estimates in John Day Reservoir. The Predation Index is intended to direct the implementation of the Predator Control Program in a measured and systematic way throughout the Columbia River Basin (Figure 3). The three main-stem reaches being considered are the lower Columbia River (Bonneville Dam tailrace to McNary Reservoir), the mid-Columbia River (Hanford Reach to Chief Joseph Dam tailrace), and the lower Snake River (Ice Harbor Dam tailrace to Hells Canyon Dam tailrace). Conceptually, the Predation Index (PI) for northern squawfish *in* Columbia River reservoirs will be a product of a predator abundance index (A) and a consumption index (C)*:

$$PI = A \cdot C \ .$$

The components of the Predation Index are currently under development. ODFW (Project 82-012) is investigating various methods which could be used for predator abundance indexing (A), e.g., CPUE and morphoedaphic index (MEI); and the USFWS (Project 82-003) is developing methodology for consumption rate indexing (C), e.g., bioenergetics modeling and stomach contents.

The specific objectives of implementing a Predation Index are:

1. To assess the magnitude of predation in various reservoirs throughout the Columbia River Basin -- relative to the baseline data in John Day Reservoir.

2. To direct the Predator Control Fishery to the sites and reservoirs, on a priority basis -- to the places where the predation problem is the worst.

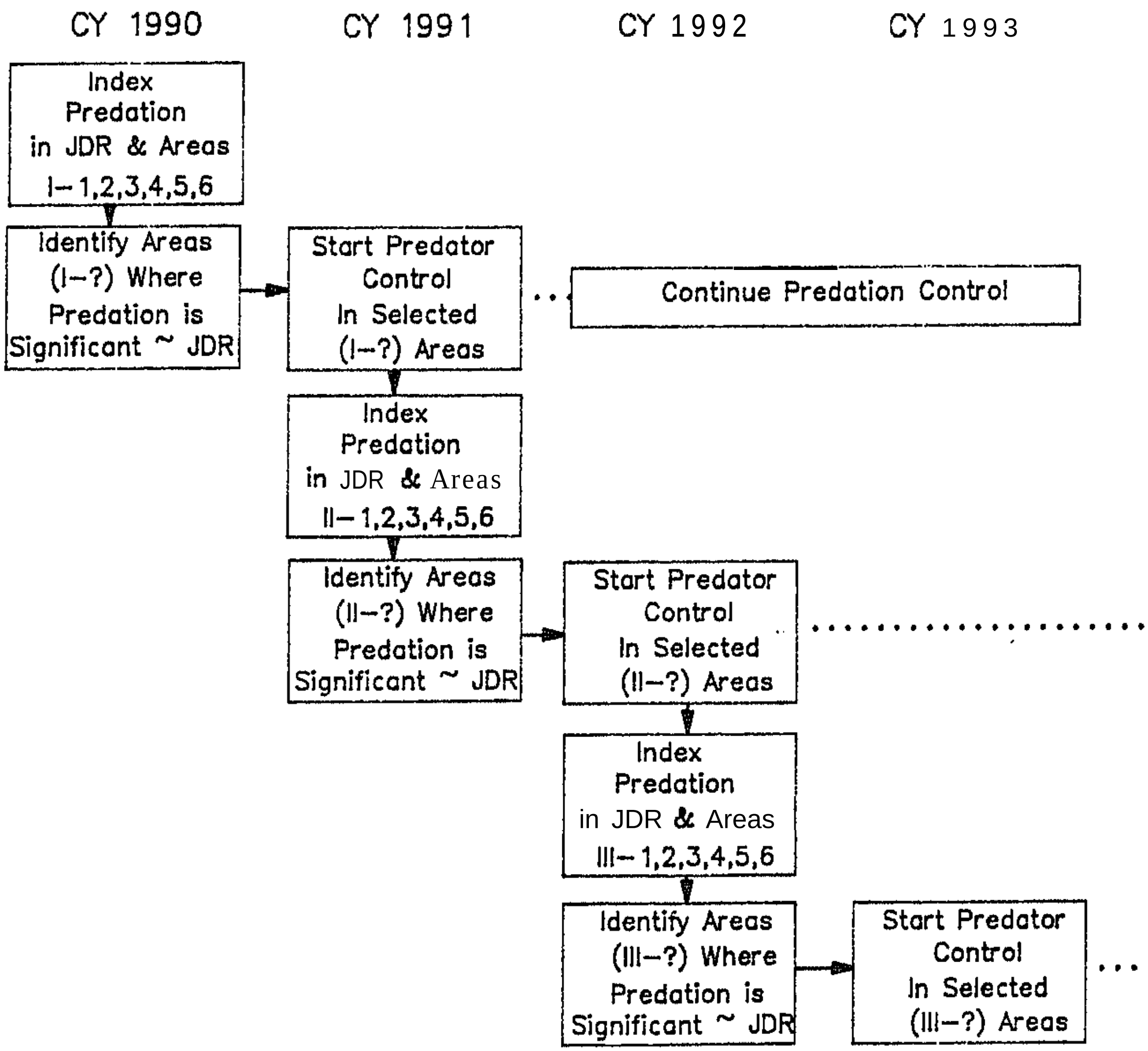


Figure 3. Stepwise implementation plan for predation indexing as a means to direct predator control fisheries in the Columbia River Basin. Predation indexing in various reservoirs is relative to John Day Reservoir (~ JDR). Roman numerals I, II, and III refer to three generic reaches of the Columbia River (approximately 6 reservoirs each) which would be indexed in 1990, 1991, and 1992, respectively.

## Sampling Design and Methods

Three methods will be used to obtain catch per unit effort (CPUE)* measures of predator abundance: gill netting (GN), electroshocking (ES), and dam angling* (DA). Gill netting and electroshocking will be conducted as part of a boat sampling program to develop the index and collect pre-treatment baseline data on predator population characteristics (e.g. age and size composition) as described under Approach C. To develop the index the boat sampling design consists of: three areas per reservoir (forebay, mid-reservoir, tailrace); during two segments of the smolt out-migration, i.e., early (approximately May) and late (approximately July); with a total effort of about 20 days of sampling per reservoir. Dam angling will be conducted continuously from April to August as part of a program to develop the index and conduct test fisheries at specific projects: with a total of about 50 days of indexing and 50 days of removal fisheries per project (see Approach B). Additionally, water samples will be collected and analyzed for salinity in order to calculate the ME1 -- which will be correlated with CPUE.

The indexing effort will be divided (approximately equally) among three years, starting in 1990 (Table 1). Areas where we will conduct boat (GN and ES) sampling in 1990 are John Day Reservoir (standard), Bonneville tailrace and reservoir, The Dalles Reservoir, McNary Reservoir, and Ice Harbor tailrace. Tentative sites for dam angling in 1990 are the tailrace and forebay of Bonneville (Powerhouse 1 and 2), The Dalles, John Day, and McNary dams, and Ice Harbor tailrace. These preliminary selections of reservoirs and dams were based on the abundance of smolts passing dams (FPC 1988), input from the RM/WBE TWG and a cross-section of the fisheries community via a "predation questionnaire", and a survey of available information on predator abundance in various reservoirs (Vigg and Burley 1989). The tentative schedule for concurrent boat indexing and pre-treatment baseline data collection (ES and GN) at specific reservoirs, the test fishery in John Day Reservoir (commercial and sport), and concurrent dam angling indexing (DA) and test fishery at all specified dams is presented in Figure 4. Dam angling will run continuously April-August, with two weeks per month of indexing (mark-release), and two weeks per month of test fishery (removal).

The boat sampling (GN and ES) will he stratified by area because it is well documented that CPUE and feeding activity of northern squawfish in John Day Reservoir may vary by orders of magnitude among areas (Vigg et al. 1988; Vigg and Burley 1989). The boat sampling will be divided by the two time periods because biological and environmental conditions are very different, and the activity, behavior, and catchability of northern squawfish vary accordingly. The early season is characterized by cold water temperature, short days, migration of large yearling salmon and steelhead, pre-spawning distribution of northern squawfish, and low feeding activity: while the late season is characterized by warm temperature, long days, migration of small sub-yearling chinook salmon, post-spawning distribution of northern squawfish, and high consumption rates (Vigg 1988). Furthermore, there may be interaction among spatial and seasonal effects. Thus by stratifying the boat sampling by reservoir area and time, we will probably average out some of the variability

* Underlined terms are defined in the Glossary.

Table 1. Spatio-temporal sampling design for indexing the lower Columbia (LC), mid-Columbia (MC), and lower Snake (LS) rivers, April-August, 1990-1992. Boat sampling (electroshocker and gill net) will be conducted for three days per area per reservoir per migrational period. Dam angling will be continuous (April through August); two weeks/month of Indexing will be conducted in conjunction with two weeks/month of Test Fishery in 1990.

| Calendar Year | Reservoir Number (reach) | Area* (F,R,T/ L,M,U) | Index Method: Boat Sampling | Index Method: Dam Angling |
|---|---|---|---|---|
| 1990 | 1. John Day Reservoir (LC) | F | X | x |
| | | R | X | |
| | | T | X | x |
| | 2. Bonneville Tailrace (LC) | T | X | x |
| | 3. Bonneville Reservoir (LC) | F | X | x |
| | | R | X | |
| | | T | X | x |
| | 4. The Dalles Reservoir (LC) | F | X | x |
| | | R | X | |
| | | T | X | x |
| | 5. McNary Reservoir (LC) | F | x | x |
| | | R | x | |
| | | U | x | |
| | 6. Ice Harhor Tailrace (LS) | T | x | X |
| 1991 | 1. John Day Reservoir (LC) | F | x | x |
| | | R | x | |
| | | T | x | X |
| | 2. Ice Harbor Reservoir (LS) | F | x | X |
| | | R | x | |
| | | T | x | X |
| | 3. Lower Granite Reservoir (LS) | F | X | X |
| | | R | X | |
| | | T | X | x |
| | 4. Little Goose Reservoir (LS) | F | X | X |
| | | R | X | |
| | | T | X | X |
| | 5. Lower Monumental Reservoir (LS) | F | x. | X |
| | | R | X | |
| | | T | X | X |

Table 1. (continued)

| Calendar Year | Reservoir Number (reach) | Area* (F,R,T/ L,M,U) | Index Method: Boat Sampling | Index Method: Dam Angling |
|---|---|---|---|---|
| | 6. Hells Canyon Tailrace (LS) | L | X | X |
| | | M | X | |
| | | T | X | X |
| 1992 | 1. John Day Reservoir (LC) | F | X | x |
| | | R | X | |
| | | T | X | x |
| | 2. Hanford Reach (MC) | L | X | x |
| | | M | X | |
| | | T | X | x |
| | 3. P. Rapids Reservoir (MC) | F | x | x |
| | | R | x | |
| | | T | x | x |
| | 4. Wanapum Reservoir (MC) | F | x | x |
| | | R | x | |
| | | T | x | x |
| | 5. Rock Island Reservoir (MC) | F | X | x |
| | | R | X | |
| | | T | X | x |
| | 6. Rocky Reach Reservoir (MC) | F | X | x |
| | | R | X | |
| | | T | X | x |
| | 7. Wells Reservoir (MC) | F | X | x |
| | | R | X | |
| | | T | X | x |

{x= index sampling1

* Area codes:
F= forebay, reservoir
R= mid-reservoir (pool)
T= tailrace, reservoir
L= lower reach, open river
M= mid reach, open river
U= upper reach, open river

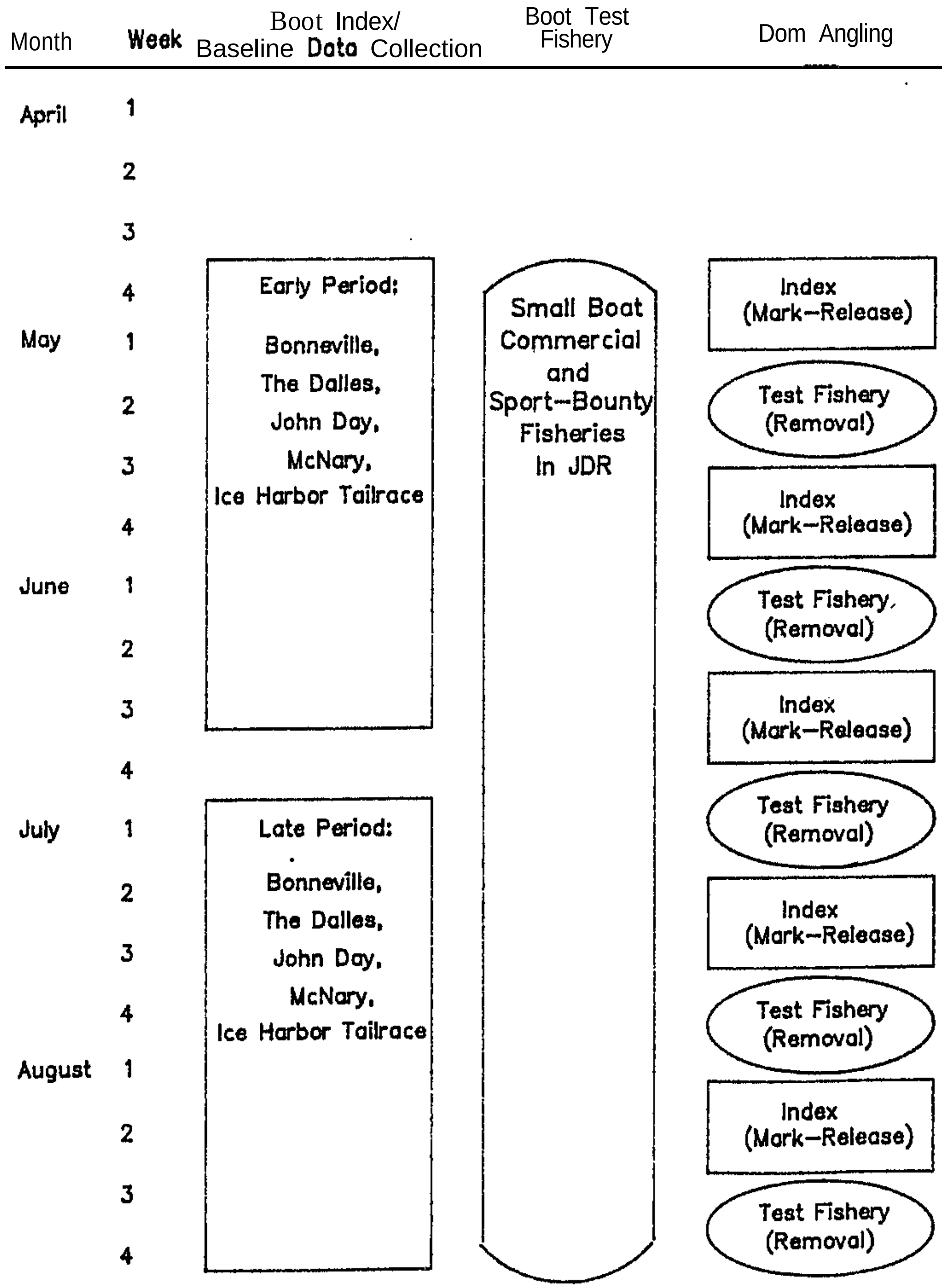


Figure 4. Logistic schedule for predator abundance indexing (rectangles) and test fishery (ovals) in various reservoirs and at dams (John Day, Bonneville, The Dalles, McNary, and Ice Harbor) on the Columbia River in 1990.

in the system. From a strictly practical (logistic) point of view, it would not be possible to get all samples taken in all (6 or 7) reservoirs in a short enough time frame to avoid temporal trends in conditions from differentially affecting the CPUE and thus biasing the results of the Predator Abundance Index. For example, the median passage (50% of run) time of yearling chinook salmon from Rock Island Dam (mid-Columbia) and Lower Granite (Snake) down to Bonneville Dam occurs in about a two week period, and the median passage of sub-yearling chinook salmon occurs in about a three week period among dams (Table 2).

## Approach B: Conducting a 1990 "Test Fishery" for Northern Squawfish Removal in the Columbia Basin

### Concept and Specific Objectives

The purpose of the Test Fishery is to determine which ***type(s) of fishery*** (subsidized commercial-bounty, sport-bounty, or dam angling) is most effective in removing northern squawfish.

The specific objectives of the 1990 test fishery are:

1. Concurrently implement three control fishery approaches in John Day Reservoir (i.e., commercial-bounty, sport-bounty, and dam angling) to test their relative efficacy in removing northern squawfish.

2. Implement dam angling at other project-specific "hotspots" in conjunction with the Predation Index: i.e. at John Day, Bonneville, The Dalles, McNary, and Ice Harbor dams.

3. Provide technology transfer of the commercial fishing methodology proposed by the current harvest technology study.

### Sampling Design and Methods

The work planned is to initiate a subsidized commercial, sport-bounty, and dam-angling test fishery in John Day Reservoir during the 1990 field season, initiate a dam angling removal fishery (in conjunction with the concurrent indexing) at other project-specific "predation hotspots" determined'by available data and community consensus, transfer the commercial harvesting technology to the private sector, and to monitor the fishery. The proposed schedule for components of the 1990 project is presented in Figure 5. There are three components of the 1990 test fishery: (1) a small-boat subsidized commercial fishery, (2) a public sport-bounty fishery, and (3) agency conducted dam angling. The relative efficacy of these fishery types will be judged on economic and biological criteria (Figure 6).

***Subsidized Commercial Fishery.*** Commercial fishery harvest technology research (Mathews et al. 1989) is evaluating methodology (how, where, when) to most efficiently harvest northern squawfish in Columbia River reservoirs, with the least detrimental impact on other fishery resources. The preliminary

Table 2. Timing of juvenile salmonid median (50%) passage past five dams in the lower Columbia, mid-Columbia, and lower Snake rivers: dates are computed as means of 1984 to 1987 (FPC 1988).

| Dam | Years of Data | Median Passage Date for Species / Group | | | | |
|---|---|---|---|---|---|---|
| | | Chinook | | Coho | Sockeye | Steelhead |
| | | Sub-yearling | Yearling | | | |
| Bonneville | 1 | -- | Apr 29 | May 9 | May 24 | May 13 |
| John Day | 2 | July 22 | May 15 | May 21 | May 26 | May 16 |
| McNary | 4 | July 9 | May 10 | May 30 | May 21 | May 17 |
| Rock Island | 3 | June 30 | May 8 | May 23 | May 10 | May 17 |
| Lower Granite | 4 | April 28[a] | | -- | -- | -- |

[a] All chinook salmon combined

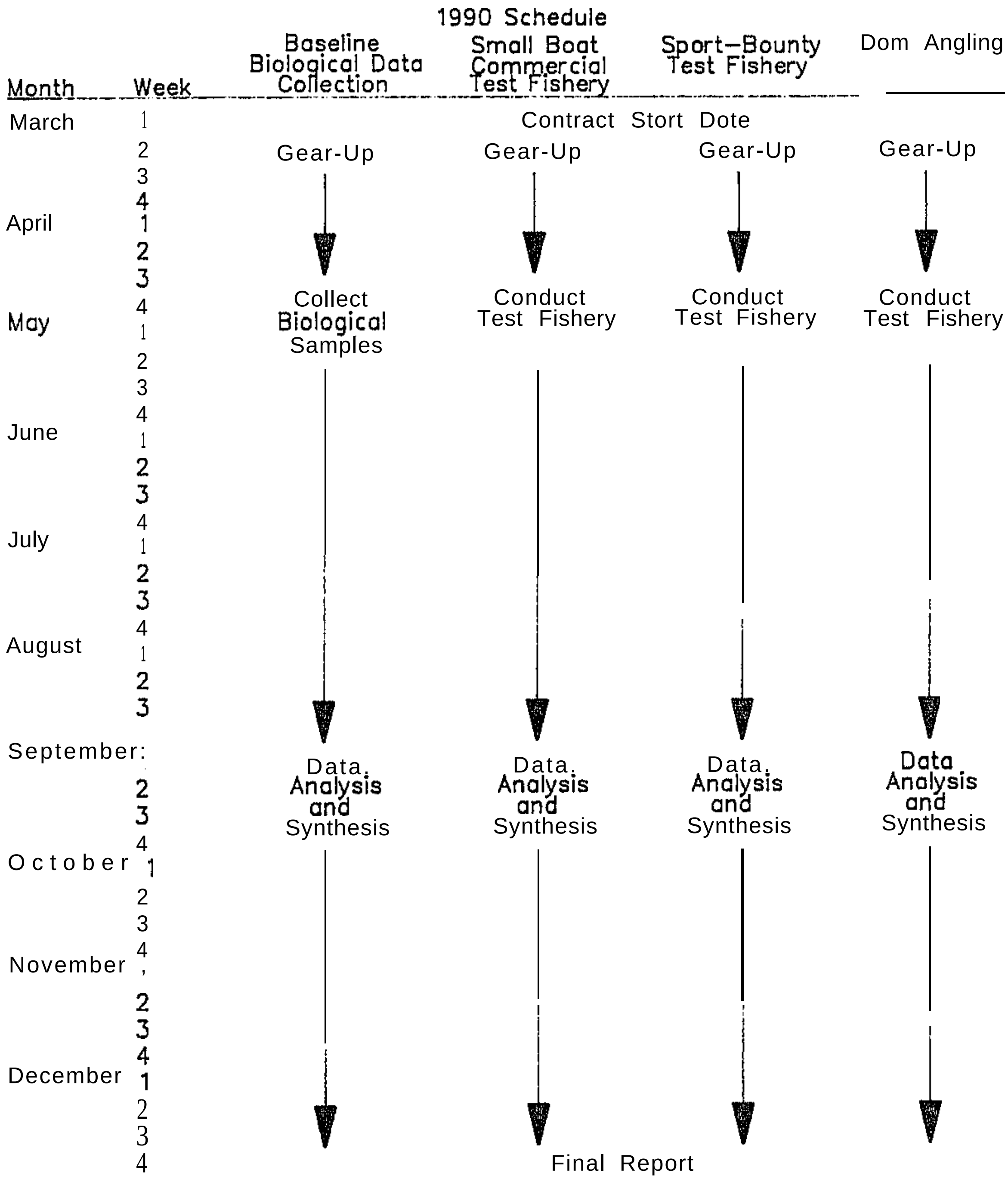


Figure 5. Schedule for 1990 test fishery and evaluation sampling, given an March 1 contract start date.

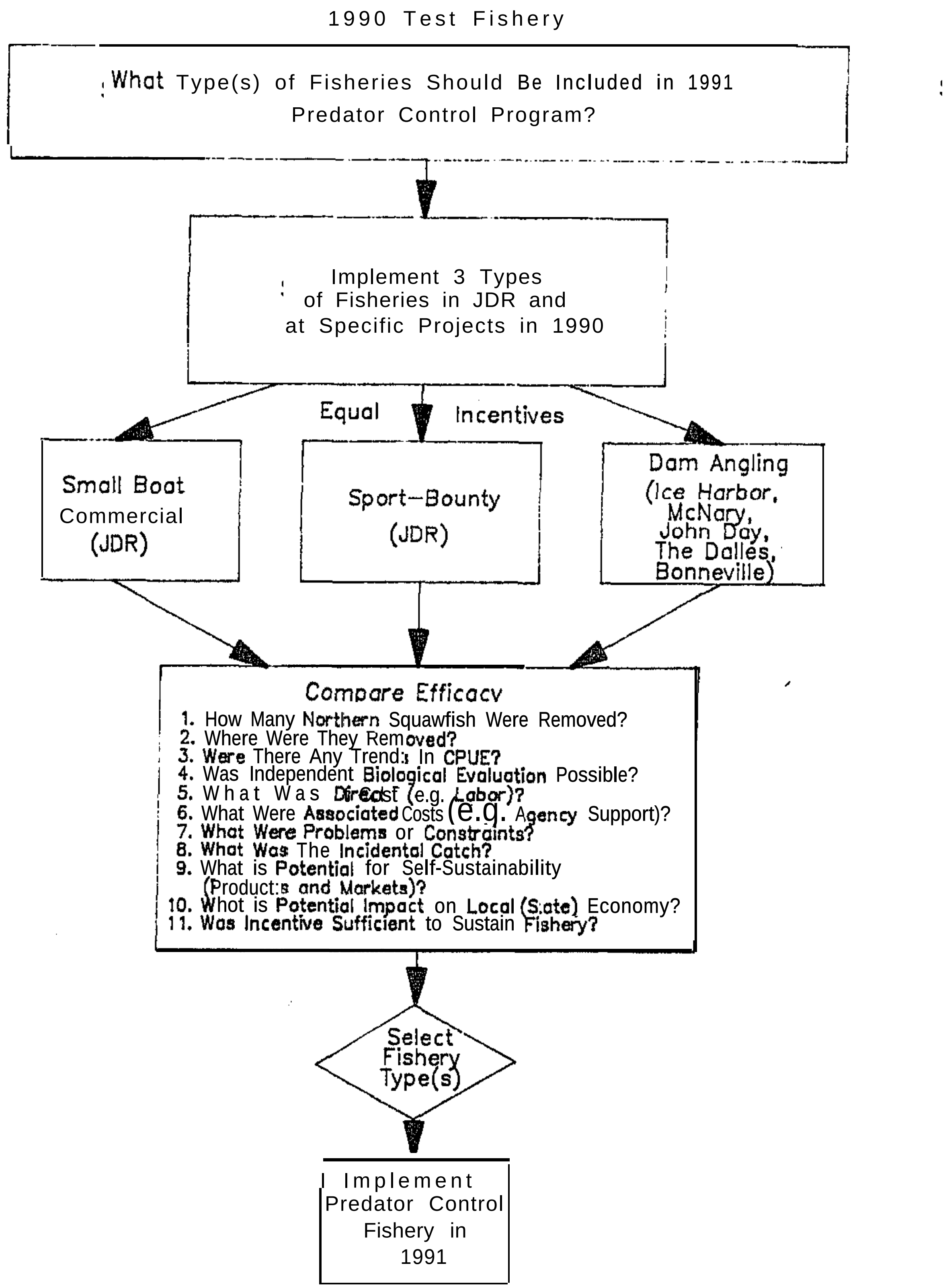


Figure 6. Components of the 1990 "Test Fishery" and criteria for selection of which fishery type(s) to incorporate into the Predator Control Program.

conclusion of this work is that longlining was the most suitable small-boat commercial fishing method, based on several criteria (Mathews et *al. 1989).* During 1990, a commercial fishery will be implemented either as: (1) a special services contract to the existing Zone 6 Indian fishermen (e.g. as a cooperative agreement with Columbia River Inter-Tribal Fish Commission); (2) a special services contract to independent fishermen (e.g. open to the public on a bid basis); or (3) using fishery agency technicians. ODFW observers on the boats would collect biological (e.g., northern squawfish harvest and incidental catch) and economic (e.g., time and cost) data and interface with both the UW technology transfer subcontract and the OSU (Hanna) economic feasibility subcontract. Mathews will support the commercial fishery component of the test fishery by facilitating the transfer of the appropriate technology to the commercial fishermen.

Thus the cooperating agencies are proposing a controlled, observed, subsidized commercial fishery which is aided by the transfer of technology from previous research. The proposed approach for technology transfer follows. Three fishermen would apply through an umbrella organization (e.g., Pacific States Marine Fisheries Commission, PSMFC) for BPA funding to cover daily operating costs (fuel, engine operation and maintenance, and opportunity wages). Fishermen would receive additionally from BPA a bonus incentive of $1 per fish caught. Such a subsidy would simulate the "reward-according-to-production" format of an unsubsidized commercial fishery. Under the subcontract to UW (Mathews) all of the longlining equipment, terminal gear, and bait would be provided to fish three boats during April-August. UW project personnel would advise and help fishermen in outfitting their boats and organizing gear. Mathews would instruct fishermen in all phases of their fishing -- times, areas, and methods of gear deployment. The UW subcontract would supply fishermen with bait in the forms found most effective -- fresh salted, or salted and frozen smolts or possibly other alternatives (e.g., earthworms or cottids). UW would periodically monitor fishing activities on the water to offer suggestions for improved efficiency, receive their input for methods to improve efficiency, and take incidentally caught food and game fish for additional tests of hooking and handling mortality. UW also proposes to conduct additional longline tests with their own research vessel. The purposes would be threefold: (1) to compare test catch rates with those of the commercial fishermen as a check on the adequacy of technology transfer: (2) to test alternative longlining ideas the fishermen may put forth (i.e., to maintain an idea and informational "feedback" mode); and (3) to do additional test fishing in the McNary Dam Tailrace boat restricted zone (BRZ).

***Sport-bounty Fishery.*** A public bounty fishery will be implemented at specific access points (e.g., Paterson, Umatilla, Arlington, and John Day River) in the John Day Reservoir. On a daily basis (weekends and three weekdays) at each access point, agency personnel will: (1) register bounty fishermen initially, (2) collect catch data at the end of the trip (i.e., northern squawfish catch, incidental catch, effort, and location of capture), and (3) dispense bounty vouchers (to be funded by BPA). Several types of bounty incentives can be tested: dollar amount per fish returned (e.g. $1); lottery tags (e.g., 10 tags at $1000); and prizes for largest and most fish per day or season (e.g., fishing gear or boat). The sport-bounty fishery in John Day Reservoir will provide a field test of its relative effectiveness in removing northern squawfish, and also provide essential data on socioeconomics and institutional constraints. Hanna et al. (1989) conducted a search of available information (scientific reports and regulations) on bounty fisheries, and found that few relevant case studies exist on the feasibility of this concept in sport fisheries. Therefore, a realistic test on a small scale is required to determine both the potential and constraints of implementing a sport-bounty fishery.

***Dam Angling.*** Dam angling will be conducted by agency technicians on a continuous basis from April to August; half of this effort will be for indexing (CPUE and fish mark-release), and half for squawfish recapture and removal. Including dam angling in the Test Fishery has two purposes: (1) to enable realistic comparison of the effectiveness of dam angling compared to commercial and recreational fisheries; and (2) to implement northern squawfish **removal** as soon as possible at high priority areas, while concurrently providing predator abundance index information.

***Harvest Technology.*** Potential alternate **removal** methods will be identified, and preliminary tests conducted by ongoing harvest technology research (Project 82-012). If judged feasible, these additional methods could be compared in 1991 to the fishery type(s) selected during the 1990 Test Fishery (Figure 7).

Approach C: Implementing a ***Test Evaluation*** Plan for the Northern Squawfish Predator Control Program in the Columbia Basin

Concept and Specific Objectives

The purpose of the "Test Evaluation"* is to field test the plan for ***economic and biological evaluation*** of predator removal.

A primary objective of the current study (Project 82-012) is to develop a strategy for evaluation of the efficacy of the Predator Control Program. There are three possible levels of evaluation (Figure 8); i.e., to predict and quantify the effects of the control fishery on: (1) northern squawfish **structure** and abundance (and associated fish community interactions), (2) survival of juvenile salmonids, and (3) ultimately adult salmon and steelhead returns. The proximate effects on the northern squawfish population will be monitored from statistics derived from the control fishery (e.g., CPUE and size **structure);** modeling will be used to simulate the secondary effects on the resident fish community, potential compensatory mechanisms, and the ultimate effects on juvenile salmonid survival. Long term monitoring (e.g., 10 to 50 years) of adult salmonid returns would be needed to attempt to assess the ultimate effects of a predator control program; and even then it probably would not be possible to isolate the individual effects of various concurrent enhancement measures. A summary of how simulation modeling provides a framework for incorporating the various aspects of the biological evaluation strategy is presented in Figure 9.

The specific objectives of the 1990 test evaluation are:

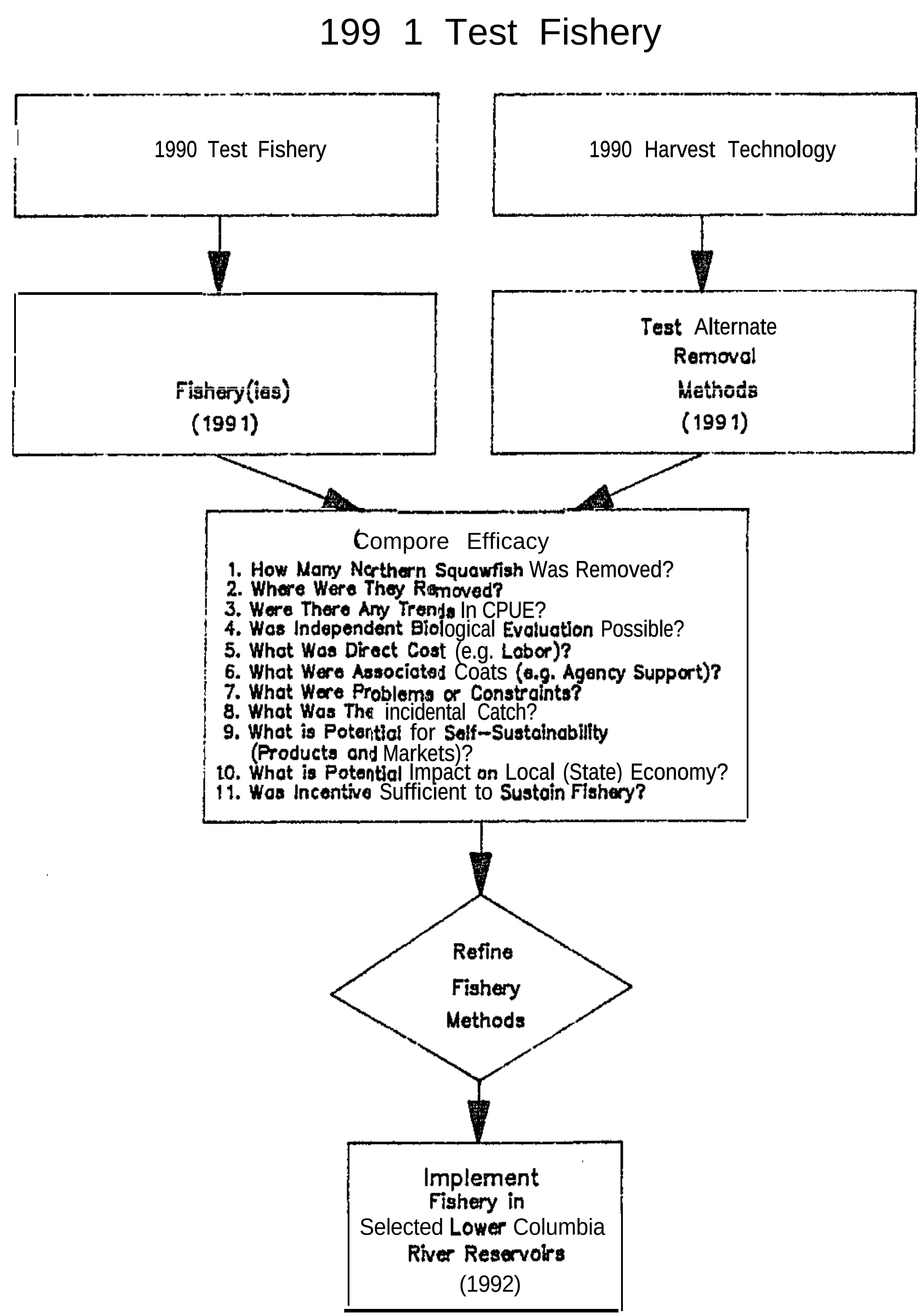


Figure 7. Test Fishery work proposed for 1991: comparison of the effectiveness of the fishery type(s) selected in the 1990 Test Fishery to alternative removal methods developed in the Harvest Technology study -- in order to refine fishery methods for implementation into the Predator Control Program.

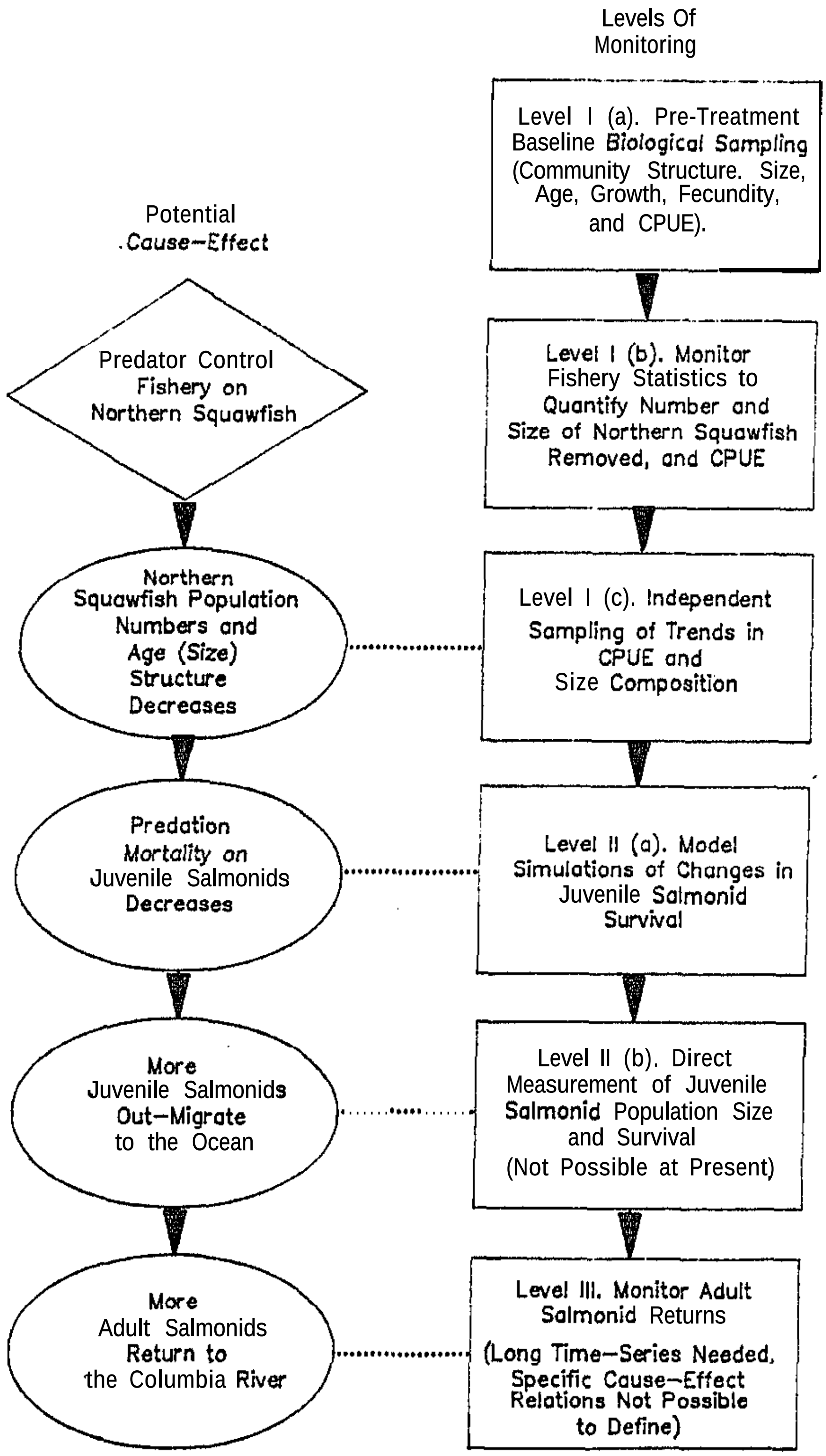


**Figure 8.** Three possible levels of biological evaluation of predator control fisheries.

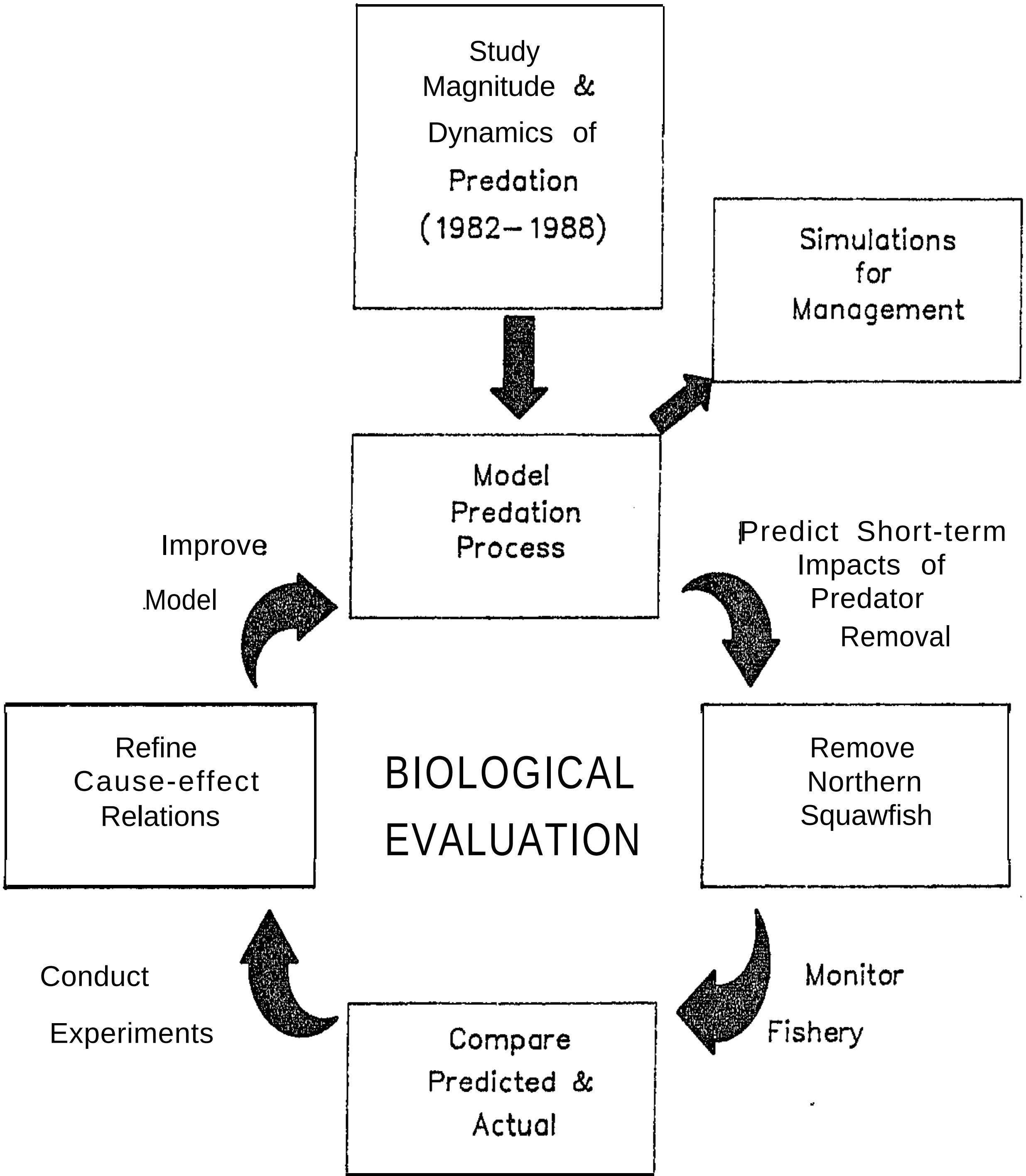


**Figure 9.** Biological evaluation of predator control fisheries -- incorporating simulation modeling.

1. Test the economic evaluation plan* -- in John Day Reservoir and at project-specific sites prior to large-scale control fishery implementation; economic evaluation data will be used to monitor fishery performance and prospects for long-term sustainability.

2. Test the biological evaluation plan* -- in John Day Reservoir, in other' specific reservoirs and at specific projects prior to large-scale control fishery implementation; biological evaluation will include collecting pre-treatment baseline biological data on predators, monitoring of-catch and size composition data in each fishery and utilization of this information to project changes in predator populations and resultant reductions in salmonid mortality via the predator control simulation model.

## Sampling Design and Methods

### Standardized Pre-treatment Baseline Data Collection

To provide a standardized pre-treatment baseline of predator biological data in all reservoirs in the Columbia River Basin for comparison of potential compensatory population dynamics before and after northern squawfish removal, community structure, relative abundance, fecundity, gonadal somatic index (GSI), age and growth, and size composition* will be measured in each reservoir prior to implementation of a fishery. As mentioned under Approach A, pre-treatment baseline data collection and boat indexing will be done concurrently. Percent species composition from the boat samples (GN and ES) will provide baseline information on the relative abundance of the predator populations and the general fish community structure. Gonad samples from northern squawfish, walleyes, smallmouth bass, and channel catfish will be taken to determine size-specific fecundity, and seasonal GSI to grossly estimate reproductive potential. Scale samples from northern squawfish, walleyes, and smallmouth bass, and spine samples from channel catfish will be collected for age and growth determinations. Length and weight of a subsample of each predator species will be taken to determine age-size keys, length-weight relations, and population size composition.

Fishery exploitation rates* and abundance of northern squawfish populations will be estimated, and assumptions tested using mark-recapture techniques. These methods will be incorporated into the ***1990 Test Evaluation*** scheme by spaghetti-tagging northern squawfish at the various dams (dam angling) and reservoirs (boat sampling, ES and GN) -- and subsequently recapturing them with the three removal fisheries and boat sampling. Exploitation estimates (recaptures in fishery/total marked) will be used to determine whether the fisheries are achieving desired harvest levels. Northern squawfish population estimates will be made from tagged fish -- to enable an independent estimate of exploitation using abundance estimates and known numbers removed (observed harvest). Population abundance estimates will also be used (if assumptions are met) to evaluate annual population changes (in conjunction with CPUE trends), and as input to the simulation modeling.

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* Underlined terms are defined ***in*** the Glossary.

Various assumptions of the population estimator (closed populations, differential mortality, and tag loss) will be accounted for using existing data and additional field tests. The assumptions of closed (localized) versus open (reservoir-wide) populations will be tested by monitoring reservoir-wide recaptures in three ways: (1) in all reservoirs by monitoring recaptures of fish at the various tailrace and forebay dam angling sites, and in the boat (GN and ES) sampling: (2) in John Day Reservoir by monitoring recaptures of squawfish in the Test Fishery (commercial and sport) -- marked at either John Day forebay or McNary tailrace; and (3) by a more rigorous test in Bonneville Reservoir from the monthly (April-August) boat sampling which would include tagging and recapturing squawfish at three reservoir areas {in addition to (1) above 1.

Simulation Modeling

The Columbia River Ecosystem Model (CREM)* incorporates both the spatial structure of the reservoir-predator-salmonid ecosystem and the processes (migration, predation, growth and movement of predators, predator fishery mortality) in a unified mathematical representation which is capable of simulating both the predator indexing and the test removal fishery operations, including the mark-recapture procedure. The output of CREM is a seasonal time series of the rates of predation on the species and types of salmonid juveniles migrating through the reservoir. CREM will also project the effect of fishing, growth and movement on the size of predator species populations which are included in the simulation. By configuring CREM to reflect the fishery structure (time and place of fishing, catch rates), the timing of migrations and the size and distribution of predator populations, the juvenile mortality resulting from the interactions of all processes can be determined. These projections can be made in a statistical or stochastic context, so that confidence intervals or variances for mortality levels can also be determined.

In order to make projections of salmonid mortality, it is first necessary to calibrate the model to the predator catch rates determined during the indexing and test removal fisheries. The calibration process is exactly analogous to calibration of a laboratory quantitative analysis instrument in which samples of a known content (standards) are analyzed and instrument controls are adjusted to produce appropriate readings. Unknown samples are then determined by mathematically relating their instrument readings to those of the known standards. In the case of the ecosystem model, the controls to be adjusted correspond to estimation of both catch rates of predators and their population size structure and spatial distribution. In research of previous years, the specific predation rates of northern squawfish were estimated by use of stomach content data from the predators; these rate parameters will be assumed to be known in the current research.

Since predator populations and catch rates are mathematically confounded in a simple, single species, short term fishery, it is important that data be available from a variety of fishery types over an extended time period and in various locations of a reservoir. This is especially important because it is also necessary to determine the movement, if present, of predator population groups. The use of data over a temporal and spatial range, and the incorporation of mark-recapture information, de-confounds the parameter values

* Underlined terms are defined in the Glossary.

of the model and makes it possible to estimate their values independently. Figure 10 diagrams the process of model calibration resulting in parameter estimates which will correctly project predator mortality and subsequent population structure. The extension to salmonid mortality levels depends upon the previously determined predation rate parameters, as referenced above.

***Parameter Estimation.*** Because of the complex interactions among parameter values and output variables in CREM, it is necessary to use a computer program incorporating a mathematical algorithm for parameter adjustment (Bard 1974) in order to make correct parameter estimates (Figure 10). This program has control over the CREM as a simulator: it provides some of the parameter values used by CREM and compares the simulated predator catch with actual catch. It then makes appropriate adjustments to parameter values and repeats this process in a loop until simulated catches are similar to actual catches. A goodness-of-fit measure, such as a correlation coefficient, coefficient of determination or normalized error sum of squares is also calculated. Since there is uncertainty as to the correct spatial structure of the predator population, as well as the degree and timing of movement of predators among spatial areas, it will be necessary to repeat this process with various configurations of CREM in order to determine an appropriate configuration.

***Salmonid Mortality Projection -- Single Reservoir.*** With a valid set of parameter values (i.e., one with a high goodness-of-fit to data measure) it is possible to simulate the salmonid migration and predation mortality process with a range of fishing effort levels, spatial and temporal configurations and types of gear to produce matrices and/or graphs of the subsequent salmonid mortality. The mortality which is of interest is not primarily that at the end of one season of fishing effort, but that at the end of multiple seasons of fishing, when a predator fishery will have an opportunity to reach maximal effectiveness.

Since the northern squawfish population will change, through normal mortality and growth processes, these changes must be taken into consideration for projection of multi-year salmonid mortality schedules. Especially because of density changes in the squawfish population due to removal fisheries, the predator population responses may be different than simple fecundity and weight growth according to rates determined from scientific literature. There may be intra-specific compensatory changes in either weight growth, population growth, spatial distribution or some combination. There might also be inter-specific changes in predation rates, weight or population growth or spatial distribution of other predator species than the targeted northern squawfish. Since these compensatory changes are largely unknown at this time, mortality changes to juvenile salmonids will be projected using only the simplest assumptions of normal squawfish growth in weight and population without special compensation and assuming the same amount and type of predator fisheries from one year to the next. The weight and population growth processes simulated in CREM will utilize capabilities added to the model by research during 1989.

***Predator Compensatory Response & Multi-Reservoir Effects.*** The overall effect of predator removal fisheries in the multi-reservoir Columbia River system will be the product of salmonid survival in each impoundment through which the juveniles pass in their downstream migration. In order to project this over-all mortality rate as the juveniles emerge from Bonneville Dam, it is

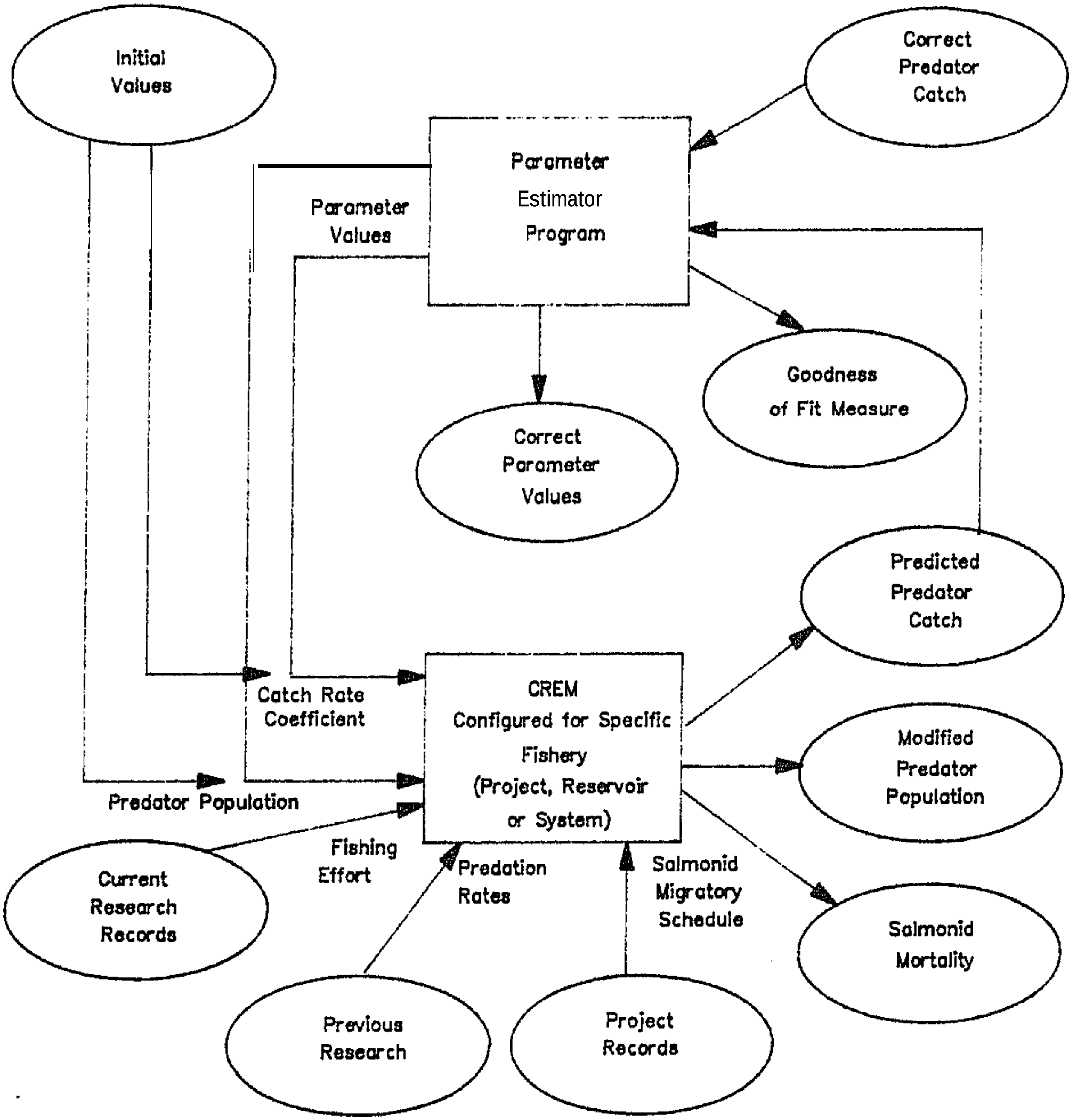


Figure 10. Columbia River Ecosystem model (CREM) slaved to parameter estimation program in order to estimate catch rate coefficients and initial predator populations using test and index fishery effort and catch. Rectangles are computer programs or sub-programs: ovals are data sets either input to or output from (or both) programs.

necessary to consider the processes described above for each juvenile group and the by-pass operations to which they are subject. On the basis of plans made during research in 1989, a version of CREM (Version 3.) will be implemented and exercised with the parameter values determined above. This will produce a total mortality projection for several passages of juveniles through the five projects involved in the removal fishery plans. Because of the time phasing over several years of the removal fishery, some parameter values for this projection will be known with less precision than others. Mortality projections made under this project phase will be appropriately qualified according to the degree of uncertainty involved in catch rates and population levels for the various projects.

This project phase will also provide an opportunity to research the possible effect of the various types of intra- and inter-specific predator responses to the removal fisheries. Fisheries literature on bioenergetic models (e.g., Kitchell 1983, Bledsoe and Megrey 1989) provides a method to determine a range of possible growth responses to changes in food supply of a fish population: such changes might occur for smaller members of the northern squawfish population if there is a density reduction of the larger northern squawfish. There are also possible changes in location of population groups which might reasonably be hypothesized due to high predator fishing intensity in some areas. The mechanisms necessary for simulation of these effects were incorporated in the CREM, Version 2., during 1989 research, these will be carried over into the multi-reservoir Version 3. Result of all of the research which is based on hypotheses about predator compensatory responses will be qualified in terms of the basis of the hypotheses and will be evaluated and used to plan the necessary research for long-term predator control and subsequent reduction of juvenile salmonid mortality in the Columbia system.

Project Organization:

The proposed Project 89-028 is a cooperative study conducted by Oregon Department of Fish and Wildlife (ODFW); U.S. Fish and Wildlife Service (USFWS); Oregon State University (OSU); University of Washington, Fisheries Research Institute (UW, FRI); and University of Washington, Center for Quantitative Science (UW, CQS). ODFW is the lead agency in the Project and is collaborating with USFWS on the Predation Indexing: additionally ODFW has cooperative agreements with OSU (Hanna) to conduct socioeconomic feasibility, with UW (Mathews) to transfer fishing harvest technology to the private sector, and with UW (Bledsoe) to incorporate simulation modeling into the biological evaluation plan (Figure 11). The subcontractors Performance Work Statements are presented in Attachment 3 and 4 (OSU), Attachment 5 and 6 (UW, FRI), and Attachment 7 and 8 (UW, CQS).

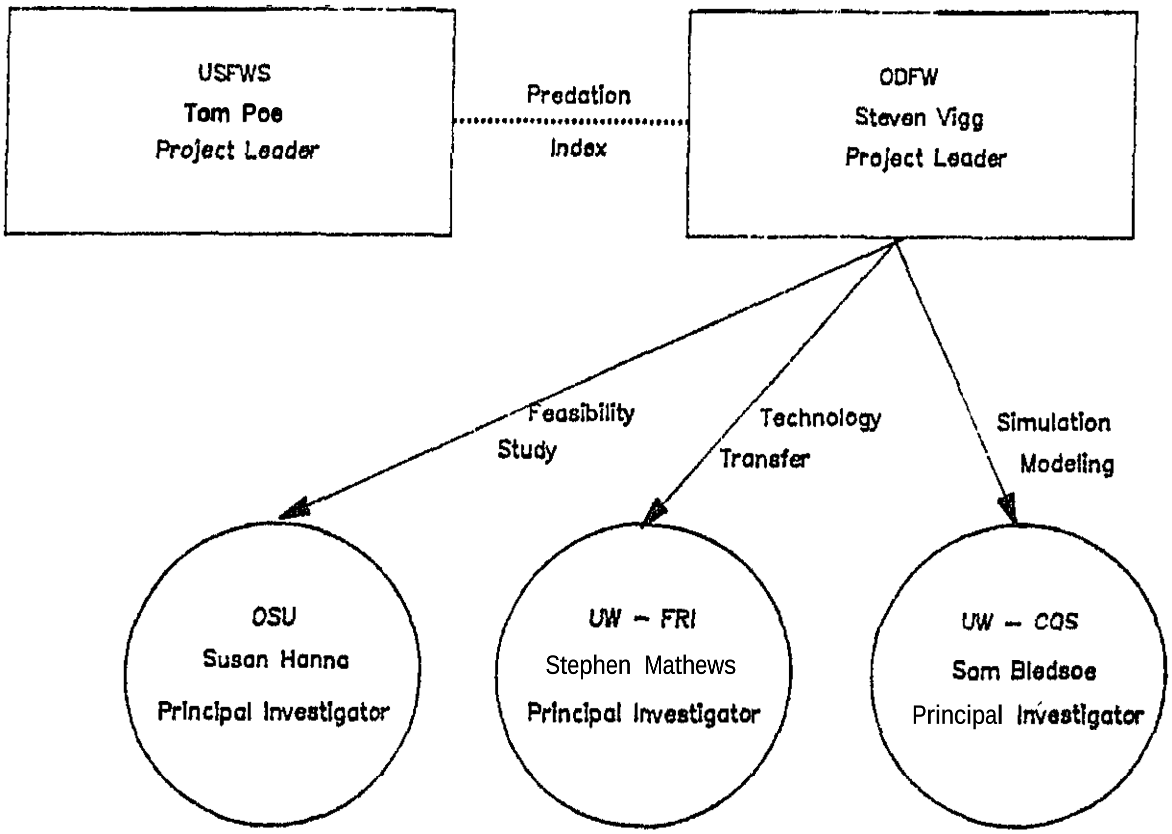


Figure 11. Organizational chart of Project 89-028, "Development of a System-wide Predator Control Program: Stepwise Implementation of a Predation Index , Predator Control Fisheries, and Evaluation Plan in the Columbia River Basin". This is a cooperative study conducted by Oregon Department of Fish and Wildlfe (ODFW); U.S. Fish and Wildlife Service (USFWS); Oregon State University (OSU); University of Washington, Fisheries Research Institute (UW, FRI); and University of Washington, Center for Quantitive Science (UW, CQS).

## REFERENCES

Bard, Y. 1974. Nonlinear parameter estimation. Academic Press, New York.

Beamesderfer, R.C., and B.E. Rieman. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia reservoir: Part III. Abundance and distribution of northern squawfish, walleye, and smallmouth bass. Pages 211-248 in T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE- AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Bledsoe, L.J. 1989. Columbia River Ecosystem Model -- Modeling approach for evaluation of control of northern squawfish populations using fisheries exploitation. Statement of Work, Subcontract to Project 82-012, Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Oregon Department of Fish and Wildlife, Contract Number DE-AI79-88BP92122 with Bonneville Power Administration, Portland, Oregon.

Bledsoe, L.J. and B.A. Megrey. 1989. Chaos and pseudo-periodicity in the dynamics of a bio-energetic food web model. (In Press) Transactions of the American Fisheries Society, Symposium Volume 6.

Brown, L.R., and P.B. Moyle. 1981. The impact of squawfish on salmonid populations: a review. North American Journal of Fisheries Management 1:104-111.

Ebel, W. 1977. Major passage problems. Pages 33-39 *in* E. Schwiebert, editor. Columbia River salmon and steelhead. American Fisheries Society Special Publication Number 10, Washington D.C.

FPC (Fish Passage Center). 1988. Smolt monitoring program, 1987 annual report. Fish Passage Center, Columbia Basin Fish and Wildlife Authority, Portland, Oregon. 112 p.

Hanna, S. 1989. Feasibility of commercial and bounty fisheries. Report B *in* A.A. Nigro, editor. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Oregon Department of Fish and Wildlife, Contract Number DE-AI79-88BP92122. Annual Report to Bonneville Power Administration, Portland, Oregon.

Hanna, S., S. Vigg, and Ii. van Huynh. 1989. Annotated bibliography on the feasibility of commercial and bounty fisheries. Appendix B-l in A.A. Nigro, editor. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Oregon Department of Fish and Wildlife, Contract Number DE-AI79-88BP92122. Annual Report to Bonneville Power Administration, Portland, Oregon.

Kitchell, J.F. 1983. Energetics. Pages 312-338 *in* P.W. Webb and D. Weihs, editors. Fish Biomechanics. Praeger, New York.

Mathews, S.B., T. Iverson, R.W. Tyler, and G. Ruggeronne. 1989. Evaluation of harvesting technology for potential northern squawfish commercial fisheries in Columbia River reservoirs. Report C *in* A.A. Nigro, editor. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Oregon Department of Fish and Wildlife, Contract Number DE-AI79-88BP92122. Annual Report to Bonneville Power Administration, Portland, Oregon.

NPPC (Northwest Power Planning Council). 1987. Columbia River Basin Fish and Wildlife Program. Adopted November 15, 1982, amended October 10, 1984, and February 11, 1987. Northwest Power Planning Council, Portland, OR.

Poe, T.P., and B.E. Rieman, editors. 1988. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Poe, T.P., P.T. Lofy, S.D. Duke, A.A. Nigro, and B.E. Rieman. 1988. Feasibility of reducing or controlling predation induced mortality of juvenile salmonids in Columbia River reservoirs. Pages 153-173 *in* T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I --Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Raymond, H.L. 1988. Effects of hydroelectric development and fisheries enhancement on spring and summer chinook salmon and steelhead in the Columbia River basin. North American Journal of Fisheries Management 8:1-24.

Rieman, B.E., and R.C. Beamesderfer. 1988. Population dynamics of northern squawfish and potential predation on juvenile salmonids in a Columbia River reservoir. Pages 274-306. in T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79- 82BP35097) Bonneville Power Administration, Portland, Oregon.

Rieman, B.E., R.C. Beamesderfer, S. Vigg, and T.P. Poe. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia reservoir Part IV: Estimated total loss and mortality of juvenile salmonids to northern squawfish, walleye, and smallmouth bass. Pages 249-273 in T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Sims, C.W., W.W. Bently, and R.C. Johnson. 1978. Effects of power peaking operations on juvenile salmon and steelhead trout migrations -- progress 1977. Final Report to U.S. Army Corps of Engineers, Contract DACW68- 77-C-0025. Coastal Zone and Estuarine Studies Division, Northwest and Alaska Fisheries Center, National Marine Fisheries Center, National Marine Fisheries Service, Seattle, Washington.

Thompson, R.B. 1959. Food of the squawfish *Ptychocheilus oregonensis* (Richardson) of the lower Columbia River. U.S. Fish and Wildlife Service, Fishery Bulletin 158:43- 58.

Thompson, R.B., and R.E. Morgan. 1959. Appraisal of the losses of juvenile salmonids to predators at Bonneville Dam. Pacific Salmon Investigations, U.S. Fish and Wildlife Service, Seattle, Washington.

Uremovich, B.L., S.P. Cramer, C.F. Willis, and C.O. Junge. 1980. Passage of juvenile salmonids through the ice-trash sluiceway and squawfish predation at Bonneville Dam, 1980. Report (Contract DACW57-78-C0058) to U.S. Army Corps of Engineers, Portland, Oregon.

USFWS (U.S. Fish and Wildlife Service). 1957. Progress report: squawfish predation study. USFWS, Office of the Regional Director, Portland, Oregon. *23 p.*

Vigg, S. 1988. Functional response of northern squawfish predation to salmonid prey density in McNary Tailrace, Columbia River. Pages 174-207 *in* T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Vigg, S., and C.C. Burley. 1989. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Report A *in* A.A. Nigro, editor. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Oregon Department of Fish and Wildlife, Contract Number DE-AI79-88BP92122. Annual Report to Bonneville Power Administration, Portland, Oregon.

Vigg, S., T.P. Poe, L.A. Prendergast, and H.C. Hansel. 1988. Predation by resident fish on juvenile salmonids in a mainstem Columbia reservoir Part II: Consumption rates of northern squawfish, walleye, smallmouth bass, and channel catfish. Pages 56-115 in T.P. Poe and B.E. Rieman, editors. Predation by resident fish on juvenile salmonids in John Day Reservoir, Volume I -- Final report of research. (Contracts DE-AI79-82BP34796 and DE-AI79-82BP35097) Bonneville Power Administration, Portland, Oregon.

Zimmer, P.D. 1953. Observations on hatchery releases and squawfish predation in Little White Salmon River in spring of 1953. Mimeo Report, U.S. Fish and Wildlife Service, Portland, Oregon.

## GLOSSARY - Operational Definitions

Age Composition - Age distribution of a fish population based on a sample, stratified by time and space.

Age and Growth - Age and growth estimates are inferred from the pattern of growth rings (number and spacing of annuli) on bony parts (e.g., scales of northern squawfish, walleyes, and smallmouth bass or pectoral spines of channel catfish) -- assuming growth in radius of bony parts is proportional to growth in length of fish and that growth slows or ceases once a year.

Angling - Fishing for personal use with one line attached to a pole held in hand while landing the fish, or with a hand-operated line without rod or reel, to which may be attached not to exceed three hooks, except on floating bass plugs (ODFW 1988; ORS 506.006).

Biological Evaluation Plan - A plan developed by BPA-ODFW Project 82-012 to evaluate the efficacy of predator control fisheries (i.e., northern squawfish removal) in terms of biological dynamics -- based on known predator removals (number and size), changes in size composition and age composition of the predator population(s), predator CPUE trends, mark-recapture estimates northern squawfish exploitation rates and population size, and simulations of predator and prey survival dynamics.

Bounty - A reward, premium, or subsidy especially when offered by a government as . . . a grant to encourage an industry or . . . a payment to encourage the destruction of noxious animals (Webster's Dictionary).

Catch Per Unit Effort (CPUE) - Number of fish, by species, captured by a standard unit of sampling effort -- standardized by duration of effort, size of sampling gear (e.g. area of nets, number of hooks or shoreline length shocked), specifications of gear (e.g., mesh size, hook size or electroshocking field), vertical and horizontal area (e.g., depth, inshore / offshore, and tailrace / reservoir / forebay), habitat-type sampled (e.g., bottom substrate and water velocity), diel time period, time of year.

Columbia River Carp and Other Nongame Fish - It is legal to fish commercially for carp and other nongame fish in the Columbia River only: (1) with an approved permit . . . . and (2) during open commercial seasons with gear authorized . . . (ODFW 1989; OAR 635-42-154).

Columbia River System (system-wide) - (= Columbia River Basin) In the context of northern squawfish predation on anadromous juvenile salmonids -- the main-stem reaches extending from from Bonneville Dam tailrace to Chief Joseph Dam on the mid-Columbia River, and to Hells Canyon Dam on the lower-Snake River.

Commercial Fishing - Fishing for profit.

Commercial Purposes - Taking food fish with any gear unlawful for angling, or taking or possessing food fish in excess of the limits permitted for personal use, or taking, fishing for, handling, processing or otherwise disposing of or dealing in food fish with the intent of disposing of such fish or parts thereof for profit, or by sale, barter or trade, in commercial channels (ODFW 1988; ORS 506.006).

Competitive Fishing - A fishing contest, where prizes or monetary rewards are offered.

Consumption Index - A rapid assessment methodology (e.g., bioenergetics modeling or stomach contents) developed by BPA-USFWS Project 82-003 to determine the relative consumption rate of northern squawfish in various Columbia River reservoirs compared to that in John Day Reservoir. It is one component of the ***"Predation Index"***, the other component being the ***"Predator Abundance Index".***

**CREM** - (Columbia River Ecosystem Model) a predation simulation model developed by Dr. Sam Bledsoe and associates, based on dynamic processes quantified during the 1982-1988 predator-prey study (Poe and Rieman, editors 1988).

Economic Evaluation Plan - A plan developed by BPA-ODFW Project 82-012 to evaluate the potential socioeconomic impacts of commercial, bounty, and recreational fishery removals of northern squawfish in the Columbia River Basin.

Exploitation Rate - The percent of the total northern squawfish population in a given reservoir which is harvested by fisheries.

**Feasibility** Study - Research to identify potential biological, socioeconomic, legal, and institutional constraints for the development of different types of fisheries (commercial, sport, and bounty).

**Fecundity** - The number of ripening and mature eggs produced by an individual female each year, usually measured just prior to spawning.

**Fish** Community - Coherent assemblages of interacting fish populations sharing the **abiotic** and biotic resources of a common environment (Evans ***et al. 1982).***

Fish Community Function - **Hierarchial** organization of fish populations based on fish size, behavioral interactions, and habitat interactions. Functional factors affecting fish community structure include: (1) species richness as a function of lake area and habitat characteristics: (2) loss of top predator; (3) direct predation or indirect competition effects: (4) energy transfer and storage as a function of body size; (5) introduction of exotic species: (6) stability as a function of community complexity; (7) dominance shifts as a function of habitat and climatic purturbations; (8) coexistence of species as a function of complementary form and behavior; (9) resource partitioning as a function of morphological differentiation: (10) growth rates, survival rates, and age of maturity as a function of ontogenetic niche shifts and species interactions: (11) food availability as a function of efficiency of **resource** sharing; and (12) community stability regulated by prey switching (Evans et ***al. 1982).***

Fish Community Structure - Species composition (present/absent), diversity (number of species), and relative abundance (percent by species) of fish populations; and the size composition of each population.

Food Fish - Any animal over which the commission has jurisdiction pursuant to ORS 506.036 (ODFW 1988; ORS 506.011). Northern squawfish is a nongame food fish. It is unlawful for any person to wantonly waste or destroy any food fish (ODFW 1988; ORS 509.112).

Game Fish - Various salmonids, ictalurids, centrarchids, acipenserids, walleye, and other listed species (ODFW 1988; ORS 496.009) -- not including northern squawfish.

Gonadal Somatic Index (GSI) - Weight of gonads (ovaries or testes) expressed as a percentage of somatic weight.

Harvest Technology - A study to determine which type of commercial fishing gear is most effective at capturing northern squawfish (a component of feasibility).

Personal Use - Taking or fishing for food fish by angling or by such other means and with such gear as the commission may authorize for fishing for personal use, or possessing the same for the use of the person fishing for, taking or possessing the same and not for sale or barter (ODFW 1988; ORS 506.001).

Pool - The reservoir, excluding the forebay and tailrace boat restricted zones.

Predator Abundance Index - A rapid assessment methodology (e.g., CPUE) developed by BPA-ODFW Project 82-012 to determine the relative density of northern squawfish in various Columbia River reservoirs compared to that in John Day Reservoir. It is one component of the ***"Predation Index",*** the other component being the ***"Consumption Index".***

Predation Index - An inexpensive, rapid assessment, order of magnitude measure of predation to identify where to implement removal fisheries: it has two components, i.e., predator abundance and consumption rate.

Predation Hotspots - Project-specific sites in the Columbia River Basin, where northern squawfish predation on juvenile salmonids is of especially great magnitude -- based on common knowledge and fishery community consensus.

Predator Control Program - An integrated approach of: assessing magnitude of predation: northern squawfish removal; monitoring of the effects on target predator species: simulation of effects on juvenile salmonid mortality: adapt[illegible] learning iterations; economic assessment: and beneficial use of public resources.

Project (Hydropower) - Dam and associated reservoir areas: i.e., a hydropower project consists of a given dam's tailrace, forebay, and reservoir.

Recreational Fishing - (= sport fishing) Fishing primarily for fun and relaxation. A recreational fisherman is one who ***uses*** authorized recreational fishing gear to capture fish for personal use only, and who does not sell or barter the catch (Pacific Fisheries Marine Commission 1982. Pacific Coastal Groundfish Plan).

Relative Abundance - (Percent Species Composition) An index of the population density of a given species relative to other species in the community -- assuming CPUE is proportional to stock density, using standardized gear.

Reservoir - The entire impounded waters between two dams (this includes the general areas: **forebay;** limnetic zone or mid-reservoir; and tailrace).

Simulation **Model** - Simulation is the process of using a model to mimic, step by step, the behavior of a system: simulation models are composed of a series of arithmetic and logical operations that together represent the structure (state) and behavior (change of state) of the system we are studying (Grant 1986).

Size Composition - Size (length or weight) distribution of a fish population based on a sample, stratified by time and space.

Sport Fishing - (=**recreational** fishing) Fishing for sport as opposed to food or profit. Sport fishermen consider factors other than catching fish as most important: relaxation, family recreation, escape from routine, being outdoors, natural beauty and esthetics (Loomis and Ditton 1987).

Test Evaluation - Implementation of the ***Biological Evaluation*** and ***Economic Evaluation*** plans on a relatively small scale in the 1990 ***"Test Fishery"*** in order to test the effectiveness of the evaluation strategy, further develop methodologies, and make any needed modifications prior to full-scale implenentation of the ***Predator Control Program*** in 1991.

Test Fishery - Implementation of different types of fisheries (commercial, sport-bounty, and dam angling) -- to field test which fishery is most effective at specific sites, and to expedite predator removal at known problem areas.

Tournament Fishing - Any fishing event or contest on public waters requiring prior registration where prizes, points, and/or money is awarded to participating anglers **(AG&F).** Tournament fishermen generally place more emphasis on the catch-related aspects of the fishing experience (Loomis and Ditton 1987). Tournaments can be divided into four categories (Riley 1985): 1. Tournament: short in duration (1-2 days), site-specific, and directed at target species; 2. Roadrunner tournament: short duration, no specific site, central data collection point (no release): 3. Derby: long duration (1-8 months), sponsored by a group: and 4. Children's derby: one day, children only, and sponsored by municipality.

Zone 6 - Columbia River fisheries management area extending from Bonneville Dam to McNary Dam.

## List of Figures

Figure 11. Organizational chart of Project **89-028,** "Development of a **System**-wide Predator Control Program: **Stepwise** Implementation of a Predation Index, Predator Control Fisheries, and Evaluation Plan in the Columbia River Basin". This is a cooperative study conducted by Oregon Department of Fish and Wildlfe **(ODFW);** U.S. Fish and Wildlife Service **(USFWS);** Oregon State University **(OSU);** University of Washington, Fisheries Research Institute **(UW,** FRI); and University of Washington, Center for Quantitive Science **(UW,** CQS).

REPORT B

# Feasibility of Commercial and Bounty Fisheries for Northern Squawfish

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CONTENTS

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We thank Steven Vigg of the Oregon Department of Fish and Wildlife (ODFW) for valuable suggestions related to market development and for his efforts in providing coordination between this project and the Harvest Technology project. We thank Steven Vigg and Craig Burley, ODFW, for their extra efforts in providing fish for market tests. Hoa van Huynh, Graduate Research Assistant at Oregon State University, did excellent work making and sustaining business contacts in the Asian community. Members of the Harvest Technology Project helped by delivering fish and were cooperative in providing data. We thank Gene Foster, Oregon Department of Environmental Quality, Water Quality Division, for his cooperation with this project and his help in overseeing the conduct of the contaminant analyses.

Thanks are also due to the owners of restaurants and markets who cooperated with us during the test marketing period: Mr. Phong, A Dong Market, Salem; Mr. Pham, 99 Market, Portland; Mrs. Nguyen, Quyen's Market, Beaverton; Mr. Tri, Golden Asia Supermarket, Portland; Mrs. Hue, Phong Phu Market, Portland; Mrs. Lane, Seven Stars Restaurant, Portland; Mr. Wong, Tuck Lung Restaurant, Portland; Mr. Ford, Henry Ford's Restaurant, Portland; and Mrs. Thai, Yen Ha Restaurant, Beaverton. We thank Roy Gilmore, fish buyer of Dallesport, WA and Jim Bahrenberg, Inland Pacific Fisheries, Ontario, OR, for their cooperation. We thank Neil Grasstiet, Grasstiet Fish Company, Fallon, NV, for generously sharing market information. Susume Kato, National Marine Fisheries Service, Tiburon, CA also generously provided information which helped to understand critical market factors.

# ABSTRACT

We report on our research conduct from February 1989 through September 1989 in the first half of the analysis of feasibility of commercial and bounty fisheries for northern squawfish (Ptvchocheilus oregonensis). Northern squawfish were provided to this project by the Predation Project of Vigg and Burley (this volume) and by the Harvest Technology Project of Mathews (this volume). Samples of northern squawfish were provided to the Oregon Department of Environmental Quality for contaminant testing. Contaminant levels tested so far indicate levels below FDA Action Levels.

We made contacts with several fish producers to outline a range of alternative end uses for northern squawfish. These included restaurants, retail markets, bait, multiple-use processing, fish meal, and animal feed. Northern squawfish were available for utilization testing from June 22, 1989 until August 10, 1989. During this time we tested three end uses: restaurants, markets, and bait. The restaurant and market trials were conducted with Asian businesses in the Portland area and in Salem. Results of these trials indicate that although the flavor and texture of northern squawfish was highly rated, boniness was a problem. Efforts will continue this fall to introduce a minced, de-boned product form to the market for testing. Frozen fish accumulated during the 1989 fishing season will be delivered this fall to Inland Pacific Fisheries, Ontario, OR, for trial in a multiple-use processing line.

An investigation into alternate market names was begun. A small number of carp (Cyprinus carpio) and suckers (Catostomus spp.) were test marketed with squawfish. The analysis of regulatory constraints to fishery development was begun and will continue this fall.

## INTRODUCTION

We began our research of the feasibility of alternative fisheries for northern squawfish (*Ptychocheilus oregonensis*) on 1 February 1989. This report summarizes our research activities and results during the first six months of the project, until 1 September 1989. Our objective in this time period was to begin the evaluation of the economic feasibility of commercial and bounty fisheries on northern squawfish, and to assist the Oregon Department of Fish and Wildlife (ODFW) in an evaluation of recreational fishery feasibility. This involved:

1. Testing various end uses for northern squawfish.

2. Assessing costs and returns of various end uses for northern squawfish.

3. Collecting data on transportation costs.

4. Assessing regulatory constraints.

Figure B-l outlines these and other research tasks which comprise the entire Feasibility Project.

## METHODS

### Sampling

This project involved sampling at both harvest and market sites. The harvest site was the John Day Reservoir of the Columbia River. Populations of northern squawfish were sampled in accordance with research objectives of two projects: the Harvest Technology Project of Mathews et al. (1990) and the parent Predation Project of Vigg and Burley (1990).

Northern squawfish were sampled by both the Predation Project and the Harvest Technology project during an eight week period June 22-August 10, 1989. Samples were provided to the Feasibility Project during this time period. Northern squawfish were caught using hook and line, gillnets, and long lines at several locations in the John Day Reservoir, as described in Mathews et al (1990). Fish size ranged from < 1 lb. to >3 lbs. Samples averaged 236 lbs. Small samples of suckers and carp were also provided to the feasibility project for market tests.

We sampled potential food market sites in Oregon urban areas. Because prior marketing information indicated that primary markets would be found in Asian communities, we limited our sampling efforts to the Portland and Salem areas, where Oregon's largest concentrations of Asians live. We visited Asian markets and restaurants in these areas to explain the research aims of the project and offer northern squawfish deliveries to those markets and restaurants interested in using northern

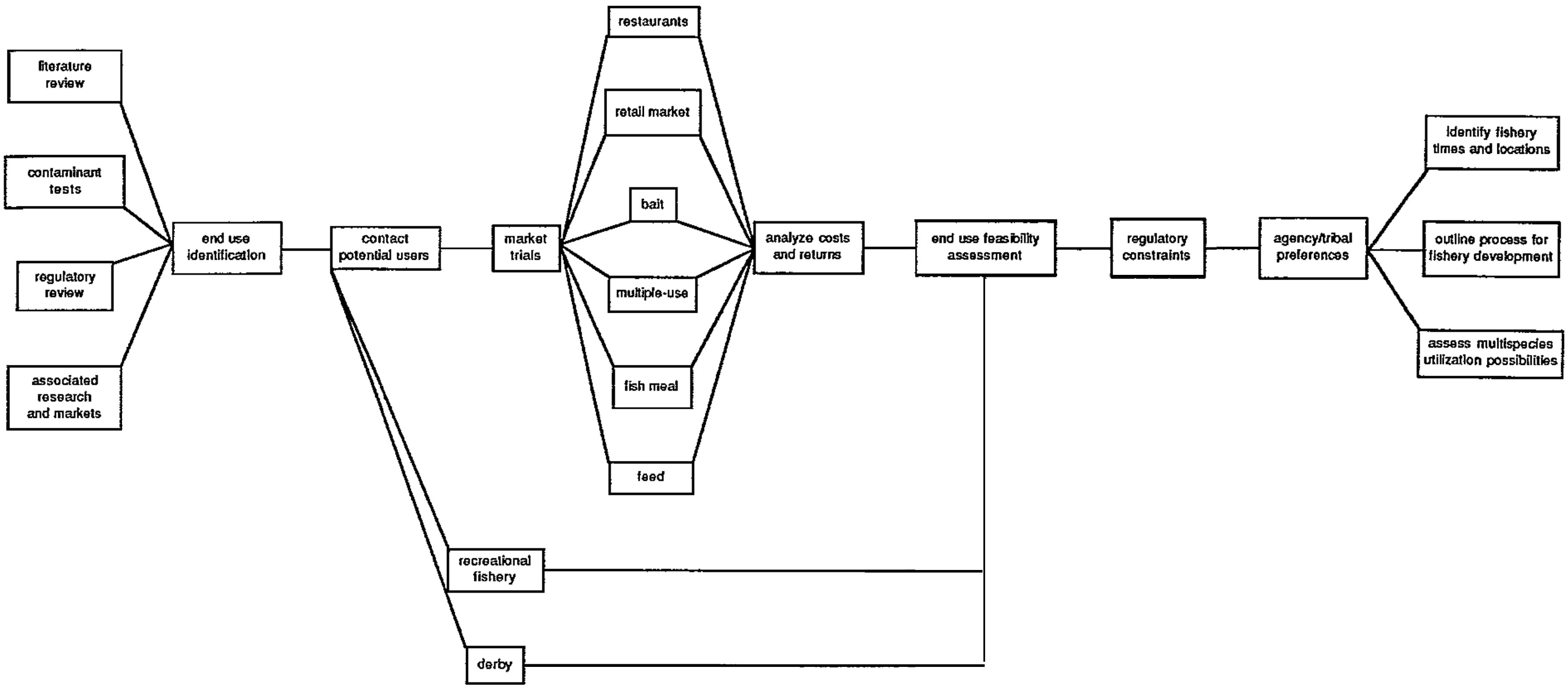



Figure B-1. Research Tasks of Project "Feasibility of Commercial and Bounty Fisheries for Northern Squawfish."

squawfish in their businesses. We contacted businesses of different sizes and with different customer groups to get as representative a sample of businesses as possible.

We requested that businesses receiving deliveries of northern squawfish provide us with information on handling costs, selling price, customer response and any other relevant marketing factors. Each business filled out a data form for each delivery. We conducted follow-up interviews with each participating business at the end of the summer delivery period. Constraints on the quantity of northern squawfish available limited the number of project participants to seven at any one time. A total of nine markets and restaurants cooperated with us over the entire sampling period. These businesses were located in Portland, Beaverton, and Salem.

Other market sites were chosen on the basis of the location of processor facilities for other identified end uses. Northern squawfish were provided as crayfish bait in Dallesport, WA. An agreement was reached with Bioproducts, Inc. in Warrenton, OR, to provide them any surplus fish from the summer's fishery for fish meal processing. Frozen fish accumulated throughout the fishery will be turned over to Inland Pacific Fisheries, Ontario, OR, for trial in a multiple-use processing line.

## Contaminant Tests

Before supplying northern squawfish for use as a food fish we wanted to ensure that contaminant levels were low enough for human consumption. We arranged with the Oregon Department of Environmental Quality (DEQ) to include northern squawfish in fish tissue tests run in May. We delivered twelve fish of different ages to the DEQ's Division of Water Quality Plating. We requested that the DEQ test both northern squawfish and carp fillets and organs for pesticides (PCB's, chlordane, DDT derivatives) and heavy metals (mercury, aluminum lead, arsenic). The DEQ does not have testing capability for either dioxins or radioactivity.

## End Uses

After preliminary discussions with people knowledgeable about northern squawfish and species with characteristics similar to northern squawfish, we decided to test northern squawfish in several end uses: restaurants, markets, bait, multiple use processing, processed fish feed and animal food. We contacted people involved with each type of use, offering free deliveries of northern squawfish for trial in exchange for data on costs and returns in each use.

Restaurants: Sacramento blackfish (Orthodon microleuidotus), a species similar to northern squawfish, has been marketed in Chinese restaurants in the San Francisco area (Kato 1987). Discussions with several people with experience in the San Francisco market indicated that the food fish market for northern squawfish would likely be an Asian ethnic market. Northern squawfish is a bony fish; Asian consumers have a relatively high tolerance for bones as well as a preference for freshwater fish. Contacts were made with several Asian restaurants in the greater Portland and Salem areas to assess interest in testing northern squawfish. We agreed to provide weekly deliveries of northern squaw-fish during the eight week sampling period in exchange for information on handling costs, sales price, and marketing problems.

Markets: For the reasons stated above, likely market sources for northern squawfish sales were determined to be Asian markets. Several Portland and Salem markets of various sizes were contacted. We agreed to provide weekly deliveries of northern squawfish to these markets in exchange for information on handing costs, sales price, and marketing problems.

Out-of-State Restaurants and Markets: We also talked with a fish buyer, a fish broker, and a fish marketer about shipping northern squawfish to California for testing in the San Francisco market.

Bait: We provided a 300 lb. delivery of frozen northern squawfish to a Columbia River fish buyer for testing as bait by crayfish fishermen.

Multiple-Use Processing: An agreement was made with Inland Pacific Fisheries, Inc., a multiple-use carp processing facility, to test northern squawfish. This production process uses fish flesh, skin, and glands. Throughout the sampling period, surplus northern squawfish were frozen and stored at the Irrigon Fish Hatchery for this use.

Fish Meal: We arranged with Bioproducts, Inc. in Warrenton, OR to sell them any surplus northern squawfish for processing into fish meal.

Animal Feed: We received a request from the Army Corps of Engineers to provide surplus northern squaw-fish to their bald eagle feeding program.

### Transportation

The gear technology project provided transportation of fish to the Portland area in eight weekly trips. Northern squawfish were transported in both live and iced forms. Live fish were held at different densities. Data were collected on various handling and transportation costs associated with each trip.

## Regulation

We reviewed the statutory restrictions concerning the use of northern squawfish, designated as a “food fish” (Oregon Wildlife and Commercial Fishing Codes 1987-1988). A description of information needed to complete an Environmental Assessment (EA) and an Environmental Impact Statement (EIS) for fishery development was provided to us by the Coordination and Review Division of the Bonneville Power Administration (BPA). Meetings will be held with ODFW personnel this fall to outline preliminary regulatory concerns related to the prosecution of a fishery on northern squawfish. Next a “straw man” implementation plan will be developed and sent out for review by agencies and tribes which have jurisdictional responsibility over fisheries of the Columbia River; members of CBFWA. The purpose of the review will be to determine the regulatory concerns of each agency related to the various end uses of northern squawfish and the potential development of a northern squawfish fishery. The fishery implementation plan will be revised until it receives final approval (Figure B-2).

### Market Name

Recognizing that the "northern squawfish" name might inhibit market development efforts, we initiated research into an alternative name more appropriate for marketing. We contacted the U.S. Food and Drug Administration to determine the protocol for assigning market names to fish. We have also begun making contacts with researchers who might know of alternative names used by tribal fishermen.

### Associated Species

In recognition of the possible multispecies nature of a northern squawfish fishery, we included carp (Cyprinus carpio) and suckers (Catostomus spp.) in various feasibility considerations. We requested samples of incidentally-caught carp and suckers from the Harvest Technology project. We were able to provide small numbers of suckers and one carp to restaurants and markets during the summer sampling period.

### Associated Research

Research is being conducted with Saltonstall-Kennedy funds on harvesting and marketing Sacramento squawfish (Ptvchocheilus grandis) from Red Bluff Dam, CA (Laveen 1988). We contacted the Technical Monitor for this project, Susume Kato at the Tiburon, CA, Lab, National Marine Fisheries Service, to share information on our project and to avoid duplication of effort.

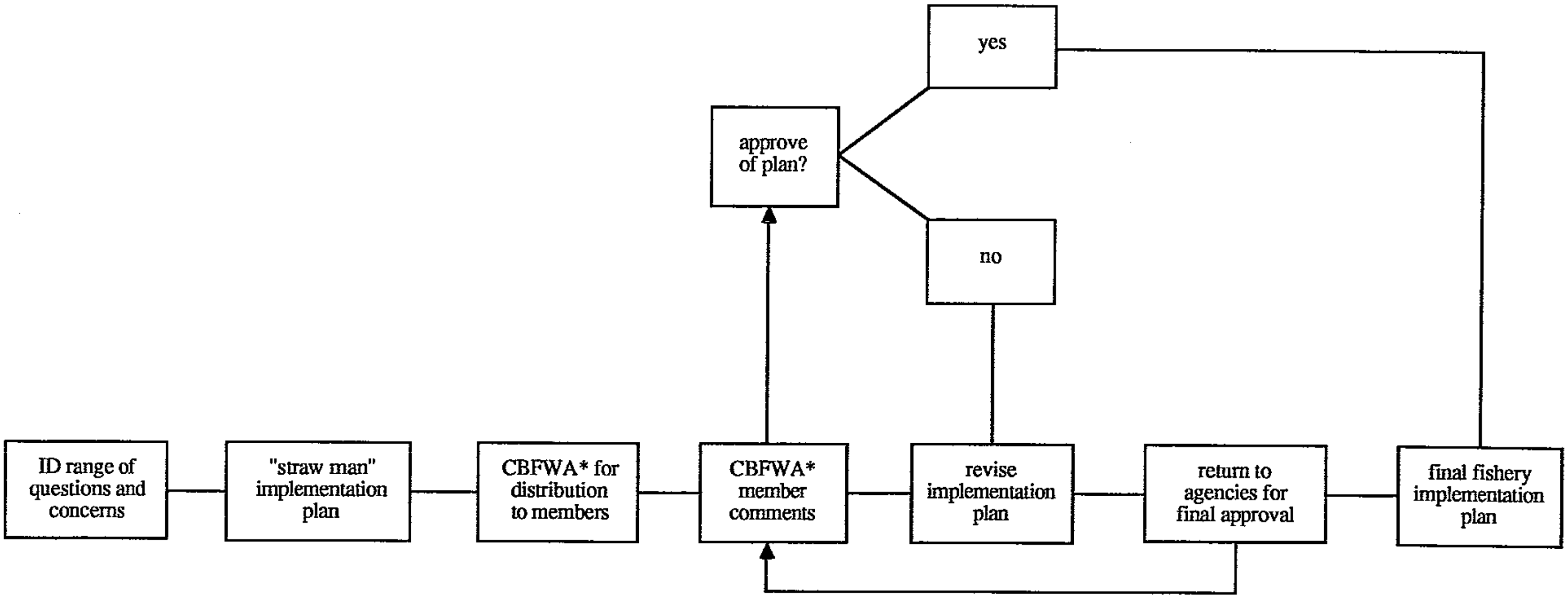
## RESULTS

### Contaminant Tests

Preliminary results of tests for organic contaminants are summarized in Appendix B-2.2. All organic contaminant levels are below FDA foodstuff action levels. FDA foodstuff action levels are enumerated in Table B-5, Appendix B-2.1. Tests for heavy metals contamination are summarized in Appendix B-2.3. Mercury, the only heavy metal for which an FDA action level exists, tests at below-action level. Both organic and inorganic contaminant testing results indicate that northern squawfish is suitable for human consumption. Tests for dioxin accumulation are yet to be done.

### End Uses

Restaurants: A total of four Vietnamese, Chinese and American restaurants in Portland and Beaverton accepted northern squawfish for trials. Three restaurants




* Columbia Basin Fish and Wildlife Authority

Figure B-2. Development of a Prototype Fishery Implementation Plan for Northern Squawfish terminated test marketing after the initial sample; the remaining two continued throughout the summer sampling period. Tables B-l and B-2 summarize the restaurant and market deliveries during the test market period. All restaurants reported that the fish were easy to handle and prepare, and all evaluated the flesh as good quality. Preparation was by steaming, frying, or sauteing. Dishes were priced between $5.60 and $7.50. Problems were reported with bones; some customers were reluctant to take the extra time required by the bones, others did not want a bony fish served to children (Table B-3).

Markets: Five Vietnamese markets of various sizes in Portland, Beaverton and Salem received samples of northern squawfish and suckers. Two markets terminated tests after the first delivery; the three remaining markets took multiple deliveries. The northern squawfish sold with varying degrees of success. The fish was priced between 29 cents and 99 cents per lb. All markets found the fish easy to prepare and were satisfied with the quality of the flesh. Market problems related to the unfamiliarity of the fish to consumers, the boniness of the fish, and the summer season when many Vietnamese are catching food fish recreationally rather than purchasing it.

The main marketing problems identified in both restaurants and markets are the unfamiliarity of northern squawfish and its boniness. Owners reported good consumer acceptance of the taste and texture of northern squawfish flesh. Fifty percent of the restaurants and markets in the summer sample were willing to test market the northern squawfish again next year if a test fishery continues. However, in light of the problem with bones, we propose to try test marketing a de-boned fish product to be used in fish cakes and fish balls. We have contacted the Astoria Seafood Lab about running a sample of northern squawfish through the deboner. We will deliver northern squawfish to Astoria this fall when sampling resumes. Sixty-three percent of the sample markets and restaurants indicated an interest in trying the deboned fish product and felt that it would sell well.

California Restaurants and Markets: Initial plans to ship northern squawfish to the San Francisco market were cancelled when both the buyer and broker reported soft markets for northern squawfish. The reported price per pound for Sacramento northern squawfish this summer was $.50, a price too low to cover transportation and marketing costs (N. Grasstiet, Personal Communication).

We will not pursue further efforts to ship northern squawfish to California at this time. We will stay in touch with the Washington fish broker and the California fish wholesaler to stay apprised of any changes in the San Francisco market that would indicate better market possibilities for northern squawfish.

Bait: Frozen northern squawfish was used successfully for crayfish bait. The fish buyer providing fishermen with the bait estimated a selling price of 10 cents per pound. Northern squawfish were readily accepted for use as crayfish bait. The feasibility of using northern squawfish for bait relative to other uses will be assessed when data on all uses is complete.

Multiple-Use Processing: Frozen northern squawfish from the summer sampling period are being stored at the Irrigon Fish Hatchery for this purpose. When sampling

Table B-l. Restaurants and Markets Receiving Squawfish Deliveries, June 22 - August 10, 1989.

| | Delivery Date | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Business | 6/22/89 | 6/29/89 | 7/6/89 | 7/13/89 | 7/20/89 | 7/27/89 | 8/3/89 | 8/10/89 |
| A Dong Market Salem | x | x | x | x | x | | x | |
| 99 Market Portland | | | | | | x | x | x |
| Quyen's Market Beaverton | x | | | | | | | |
| Golden Asia Supermarket Portland | x | x | x | x | x | x | | |
| Phong Phu Market Portland | | | | | x | x | | |
| Seven Stars Restaurant Portland | x | | | | | | | |
| Tuck Lung Restaurant Portland | x | | | | | | | |
| Henry Ford's Restaurant Portland | x | | | | | | | |
| Yen Ha Restaurant Beaverton | x | x | x | x | x | x | x | x |

Table B-2. Form, Number, and Weight of Fish Delivered to Restaurants and Markets, June 22 - August 10, 1989.

| | Deliverv Date | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6/22/89 | 6/29/89 | 7/6/89 | 7/13/89 | 7/20/89 | 7/27/89 | 8/3/89 | 8/10/89 |
| No. Deliveries | | | | | | | | |
| iced | --- | 3 | 3 | --- | 4 | --- | 3 | 2 |
| live | 6 | --- | --- | 3 | --- | 4 | --- | --- |
| No. Fish Delivered | 99 | 63 | 99 | 10.5 | 104 | 135 | 117 | 60 |
| Wt. Fish Delivered | 250 | 187 | 228 | 270 | 260 | 338 | 303 | 150 |

Table B-3. Summary of Restaurant and Retail Market Evaluation of Squawfish, June 22 - August 10, 1989.

| | |
|---|---|
| Preferred Size | < 2 Ibs. |
| Preferred Form | head on, gutted |
| Ease of Handling | good |
| Average Selling Price | |
| restaurant dish | $6.55 |
| retail market | $.76 per lb. |
| Preparation | steamed, fried, stewed |
| Taste | good |
| Texture | flakey |
| Customer Response | hesitant to somewhat positive |
| Marketing Problems | bones<br>fish available recreationally |
| Alternate Product Form | deboned, minced |

resumes in the fall, we will deliver at least 2,000 pounds of fish to Inland Pacific Fisheries for experimentation in this production process. A sample of 100 Ibs. of frozen northern squawfish has been transferred to this business for initial testing.

Fish Meal and Animal Feed: We intend to use surplus northern squawfish available during the fall sampling period for these two purposes.

We will collect cost and return data on tests of northern squawfish in multiple-use processing, fish meal processing, and animal feed. When we have full information on the costs and returns of the full range of end uses we will evaluate the relative economic feasibility of each use.

## Transportation

Both live and iced fish transported well to the market. Live fish transported in tanks were vigorous upon delivery in Portland. Live fish iced in Umatilla were still alive on delivery to Portland, five hours later. The biggest quality problem occurred with northern squawfish that had been dead a day by the time of delivery. The skin of these fish became mottled in color. The mottling was primarily a cosmetic problem; flesh quality was not affected. The components of transportation costs are summarized in Table B-4.

## Regulation

The first regulatory review meeting was held with ODFW personnel in September. Issues related to the development of a 1990 test fishery on northern squawfish were discussed. These issues included the necessary components of a review process before initiation of a test fishery, the timing of the plating process, and the identification of fishery participants. Further meetings will be held in October to plan for agency input into the test fishery plan. Following these meetings, a preliminary “straw man” fishery implementation plan will be developed and presented to other agencies with Columbia River fishery jurisdiction for their reaction and revision (Figure B-2).

## Market Name

The test marketing of northern squawfish in Asian restaurants and markets provided mixed results on the need to provide a market name for northern squawfish. One market owner felt very strongly that the name should be changed. Others felt indifferent about the name. Efforts will be made this fall to pursue literature which would identify an historical name used for northern squawfish that might serve as a market name.

Table B-4. Cost Components of Squawfish Deliveries to Portland, Sampling Period 6/22/89 - 8/10/89.

| | |
|---|---|
| Total Number of Deliveries | 8 |
| Delivery Vehicle Types | 1) 1 ton flatbed truck<br>2) 1/2 ton pickup truck<br>3) Toyota truck |
| Average Number of People Delivering | |
| To Portland | 1.25 |
| Around Portland | 2.13 |
| To Salem | 1.00 |
| Average Trip Mileage (Umatilla-Portland round trip) | 398 miles |
| Average Delivery Time | 9.1 hrs. |
| Average Number of Fish Delivered | 98 |
| Average Weight of Fish Delivered (estimated) | 244 lbs. |
| Average Fuel Use per Trip | 33.9 gal. |
| Average Fuel Cost per Trip | $40.74 |
| Average Ice Cost per Trip Used | $13.76 |
| Average Oxygen Cost per Trip Used | $19.00 |
| Delivery Equipment Purchase Cost | |
| Ice Chests | $84.00 |
| Holding Tank | $272.00 |
| Garbage Cans (carrying tanks) | $72.00 |

## Associated Species

A small number of suckers and one carp were provided to markets and restaurants during the test marketing period. The carp sold well with no reported problems. The suckers also sold in one market, but less well. The main marketing problem reported for suckers was the small ratio of flesh to head and bones.

## Associated Research

The harvest technology portion of the Red Bluff Dam project is proceeding well. This project is experimenting with fish traps placed in the vicinity of fish ladders. However, no marketing of northern squawfish is possible due to dioxin levels recently reported in northern squawfish flesh. The harvested northern squawfish are currently being used for hagfish bait (S. Kato, Personal Communication).

# DISCUSSION

## Contaminant Tests

Based on tests performed to date, contaminant levels in northern squawfish appear to be low enough to market northern squawfish as food fish. Unless the dioxin tests indicate a problem, we will continue to pursue food uses for northern squawfish. We have proposed that funding for dioxin tests be included in the 1990 Test Fishery budget. Dioxin tests will be contracted by the Oregon Department of Environmental Quality Water Quality Division.

## End Uses

Restaurants and Markets: Based on consumer tests of northern squawfish in Asian restaurants and markets from June to August, it appears that northern squawfish have good marketing potential in these areas only with a modification of product form. To gain consumer acceptance the fish should be kept in the market for longer periods of time and should be marketed in an alternative form. We feel that deboned minced fish has the greatest potential for sustained market acceptance in both restaurants and retail stores.

Bait: The use of northern squawfish as bait is acceptable but is a low-valued use. We will collect further data on the likely quantity demanded for this use; our prior expectation is that the bait market would absorb relatively small quantities of northern squawfish.

Multiple-Use Processing, Fish Meal, and Animal Feed: Further experiments this fall will determine how the alternatives of multiple-use, fish meal, and animal feed compare to the use of northern squawfish as food.

Kato, S. 1989. National Marine Fisheries Service Tiburon Lab, 3150 Paradise Drive, Tiburon, CA Personal communication.

Laveen, W.D. 1988. Squawfish commercial harvesting and marketing project. Saltonstall-Kennedy Project, 1988-1989.

Mathews, S.B., T. Iverson, R.W. Tyler, and G. Ruggeronne. 1990. Evaluation of harvesting technology for potential northern squawfish commercial fisheries in Columbia River reservoirs. Report C in A.A. Nigro, editor. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Oregon Department of Fish and WIldlife, Contract Number DE-AI79-88BP92122. Annual Report to the Bonneville Power Administration.

Oregon, State of. 1987. Oregon wildlife and commercial fishing codes. Oregon Department of Fish and Wildlife, PO Box 59, 506 SW Mill St., Portland, OR 97207.

Nigro, A. and S. Vigg. 1989. Developing a predation index and evaluating ways to reduce juvenile salmonid losses to predation in the Columbia River Basin. BPA Project 82-012.

Vigg, S., and C.C. Burley. 1990. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Report A in A.A. Nigro, editor. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Oregon Department of Fish and Wildlife, Contract Number DE-AI79-88BP92122. Annual Report to Bonneville Power Administration, Portland, OR.

## Transportation

Transportation of northern squawfish to market was not a particular problem. Northern squawfish are hardy and were able to resist stresses of moving when handled properly. The mottling of northern squawfish skin within one day after death presents some cosmetic difficulties to marketing.

## Regulation

Regulations pertaining to "food fish" prevent "wanton disposal" of northern squawfish and require utilization once harvested (Oregon Wildlife and Commercial Fishing Codes 1987-1988). Further regulatory concerns expressed by ODFW personnel include incidental catch of game species, impacts on wildlife food sources, and harvest rights, Review of the fishery implementation plan by members of the CBFWA is likely to identify additional regulatory concerns regarding the development of a fishery on northern squawfish.

## Market Name

The name "northern squawfish" does not appear to be a particular hindrance to marketing in the Asian market, but could be a problem if utilization occurs outside the Asian community. We will pursue alternative market names to propose to the FDA.

## Associated Species

We will request that carp and sucker be included in northern squawfish deliveries received from the Harvest Technology project during their fall fishing period. These fish will be included in as many of the northern squawfish utilization tests as possible.

## Associated Research

We will continue to stay in contact with the northern squawfish research being conducted at Red Bluff Dam, CA. We will be paying particular attention to alternative utilization methods of harvested northern squawfish from that project.

## REFERENCES

Grasstiet, N. 1989. Owner, Grasstiet Fish Company, 12206 Carson Highway, Fallon, NV, 89406. Personal communication.

Kato, S. 1987. Squawfish investigations. Unpublished Manuscript, National Marine Fisheries Service Tiburon Lab, Paradise Drive, Tiburon, CA.

APPENDIX B-l.

# Annotated Bibliography on the Feasibility of Commercial, Sport and Bounty Fisheries

Prepared by

Susan Hanna, Steven Vigg, and Hoa van Huynh

APPENDIX B-l.
Annotated Bibliography on the Feasibility of
Commercial, Sport and Bounty Fisheries

Adams, G.F. 1978. An historical review of the commercial fisheries of the boreal lakes of central Canada: their development, management, and potential. Pages 347-360 in Selected coolwater fishes of North America, R.L. Kendall, ed., American Fisheries Society Special Publication No. 11.

Abstract: A chronology of the development and subsequent decline of commercial fisheries (whitefish, walleye and sturgeon) on the boreal lakes of central Canada is presented. Historically, development of the remote northern fisheries was based on welfare objectives rather than economics; presently government agencies have responded to declining conditions by providing subsidy and incentive programs that have the potential to further stress the fish stocks, Quota control of harvest was a positive action toward prevention of overutilization by the commercial fishery, but measures were not taken to prevent overinvestment in the industry and the decrease in profits to fishermen. From a strict economic perspective, the fishery resources of this region are being mismanaged under a policy that does not result in a positive net return in harvested fish to either the fishing industry or the public. If a policy of managing the fisheries as common property is continued, there will be a pervasive tendency for the cost of production to exceed the value of production.

The management implication of this case study is that effective fisheries programs require: 1) a recognition and respect for the value of fisheries resources; 2) a real effort by fisheries institutions to eliminate the fragmented approach to management; 3) an acceptance and implementation of the experimental "adaptive management" approach, and 4) an immediate transfer of insights and information directly to planning and policy-making.

Although the fishery discussed in this paper is quite different from the proposed fishery on northern squawfish, some of the management implications of this case study are important. In recognition of the potential value of a commercial squawfish fishery on the Columbia River, development should proceed on a sound economic basis rather than by dependence on government subsidies. A controlled-harvest limited entry fishery could be managed to prevent problems which commonly occur in open access fisheries. Coordinated planning and development is important for effective management of the fishery resource. Harvest strategies should be based on indices that incorporate broad ecological relationships and fish community structure. This point is especially relevant since the resident fish community structure will likely be modified in order to manage for anadromous salmon species. Harvest strategies designed as adaptive management experiments would be compatible with the NPPC philosophy of adaptive management. Adaptive management has important implications for the development of a fishery within the context of a plan which evaluates the efficacy of control fisheries as they proceed.

Keywords: fisheries development, economics, open access, limited access, adaptive management, agency coordination.

American Fisheries Society. 1982. Monetary values of freshwater fish and fish-kill counting guidelines. American Fisheries Society Special Publication No. 13.

Abstract: This paper was prepared by the Monetary Values of Fish Committee of the American Fisheries Society and by the Pollution Committee of the Southern Division of the American Fisheries Society. The manuscript contains a set of monetary values of freshwater fish that may be used, in conjunction with standard sampling programs, to assess the value of fish destroyed in fish kills, in fishery mitigation efforts, in the preparation of environmental impact statements, and in the evaluation of competing water uses. The monetary values concept is based on three premises: 1) fish are resources with tangible value to the public and to the aquatic ecosystem; 2) when fish are destroyed and blame can be assigned compensation to the public agency responsible for management is required; 3) hatchery production costs provide the most reasonable source of fish value information. Values are assigned to various fresh water game, nongame, and commercial species on both a per-pound and per-fish basis. There is explicit recognition of the fact that damages from fish kills are greater than just the monetary value of the lost fish and extend to costs of investigation and clean up.

Although several Cyprinids are listed, squawfish is not one of the species assigned a monetary value in this report. However, if development of a fishery on squawfish proceeds, valuation techniques such as those outlined here will be useful for fishery impact assessment and valuation. This manuscript will be soon be reissued with updated values.

Keywords: freshwater fish, values, fish kills, mitigation, assessment.

Anderson, L., A. Ben-Israel, G. Custis, and C. Sarabun. 1981. Modeling and simulation of interdependent fisheries, and optimal effort application using mathematical programming. In Applied Operations Research in Fishing, K.B. Haley, ed., Vol. 10, NATO Conference Series. New York: Plenum Press.

Abstract: In this paper both simulation and mathematical programming techniques are discussed as approaches to the analysis of fisheries management policies. Simulation modeling provides the best tool at present for evaluating alternative management policies in fisheries with complex interactions. Mathematical programming can be used under more simplified assumptions to determine optimal harvest levels and optimal effort allocation in fisheries, subject to relevant constraints. Fisheries interdependencies considered in this paper are both biological and technological. Biological interdependencies exist when fish stocks have either competitive of predator-prey relationships. Technological interdependence exists when the harvest of one stock of fish leads to the bycatch of another stock. The simulation model incorporates both types of interdependencies. The mathematical programming model derives optimal

allocations of effort according to a specified maximization criterion, subject to specified constraints.

Development of a fishery on northern squawfish on the Columbia River will very likely involve the development of management policies which will need to incorporate the biological interdependence between squawfish and salmonids. Mathematical programming may offer a tool for arriving at the appropriate harvest level for squawfish, once the relevant constraints are defined.

Keywords: fisheries, interdependence, biological, technological, simulation modeling, mathematical programming.

Beddington, J. and R. May. 1977. Harvesting natural populations in a randomly fluctuating environment. Science 197:463-465.

Abstract: As fishing effort and yield increase, fish populations that are being harvested for maximum sustainable yield (MSY) will be more sensitive to and take longer to recover from environmentally imposed disturbances. One consequence of this is that the variability of the yield, as measured by the coefficient of variation, increases as the point of MSY is approached. When overexploitation has resulted in a population smaller than the population associated with MSY, high effort levels produce a low average yield with a high variance. These observations are consistent with observed trends in several fisheries. The authors expect that these effects will be more pronounced for harvesting strategy based on constant quotas than for one based on constant effort. The same conclusions apply of the goal is to maximize the present value of the discounted net economic revenue from the fishery.

If a sustainable fishery is to be developed on northern squawfish for the purpose of predator control, the stock dynamics outlined in this article would be important to know. The anticipation of these effects of MSY harvest levels will help avert some undesirable consequences.

Keywords: fishery harvest, MSY, variability, sustainability, quotas, effort.

Berkes, F. and D. Pocock. 1987. Quota management and “people problems”: a case history of Canadian Lake Erie fisheries. Transactions of the American Fisheries Society 116:494-502.

Abstract: This paper presents a case-study of harvest quotas allocated to individual fishermen in the Canadian Lake Erie commercial fisheries (rainbow trout, smelt, yellow and white perch, white bass, and walleye). The experience reported encompasses four years of plan development and three years of implementation. The recent trend in commercial fisheries management is toward limited entry with harvest quotas. An allocated catch quota system directly counters the common property concept, since the quota represents property rights to the resource. The quota also directly controls the total amount of fish that can be landed. The major issue underlying quota implementation in Lake Erie was fish stock assessment. A good biological data base and subsequent monitoring are required to scientifically estimate the total allowable catch of each species. Other issues were the political problem of how to allocate the total catch among eligible fishermen and enforcement of regulations. Comanagement by fishery managers and fishermen helped solve problems of catch allocation and enforcement.

Political and social considerations (equity) were more important to fishermen than economic efficiency. A research protocol is outlined for implementation of a quota system. Baseline data are needed, not only on fish stocks, but also on harvest technology, extent of capitalization,and socioeconomic characteristics of fishermen. Evaluation of the success or failure of the quota system in terms of specific criteria relating to the objectives of the management plan is essential.

This article has important implications for the development of commercial fisheries in northern squawfish in Columbia River reservoirs. A controlled, limited-entry fishery would total harvest quotas would probably have the best probability of achieving management objectives. Scientific evaluation of both biological and socioeconomic factors are necessary in order to implement the fishery and to demonstrate the efficacy of a predator control fishery to enhance salmonid populations.

Key Words: fishery regulation, harvest quotas, allocation, comanagement, freshwater fisheries.

Bishop, R.C. and K. Samples. 1980. Sport and commercial fisheries conflicts: a theoretical analysis. Journal of Environmental Economics and Management 7:220-233.

Abstract: The thesis of this paper is that commercial fisheries and recreational fisheries are often competing for a finite resource. Policy decisions to resolve these conflicts should be based on sound economic analyses at both the theoretical and empirical levels. A recreational component was added to a standard optimal control model of commercial fishing to identify public decision variables for optimal fish stock levels and optimal allocation of harvest between commercial and sport fisheries. A predator-prey component was added because of potential interactions between commercially important prey species (alewife) and recreationally important predators (salmon). Conclusions from the modeling were: 1) multiple use of fishery resources may be optimal; 2) the relative merits of sport and commercial fishing must be compared at optimal (not just existing) population levels; 3) it is important to consider benefit and cost functions over a variety of population sizes when evaluating alternative management strategies; 4) when more than one species of fish is involved, interactions such a predator-prey relations must be considered. The authors also question the point of view that sport fishing should be favored over commercial fishing since it is inherently more valuable; the comparison of values used is often invalid because the market value of commercial fish is compared to the value of the entire recreational experience.

The model development presented in this paper is relevant to the question of the economic value of developing recreational versus commercial fisheries on northern squawfish. However, the relative value of the two types of fisheries on squawfish is of secondary importance, because the major social benefit will probably be the enhancement of salmonid production. Therefore the primary criterion is the effectiveness of a fishery type in sustaining a reduction in squawfish populations, not the value of the fishery products. The model is also relevant to squaw&h-related problems because it includes predator-prey interactions. In our case the commercial fishery would be developed on the predator instead of the prey; in this way the squaw-fish fishery has the potential to enhance both sport and commercial fisheries on salmon and steelhead. The predator-prey mechanism developed to evaluate conflicting use in this model may be a basis for further development in analyzing the synergistic effects of the salmonid and squawfish fisheries on the Columbia River.

Key Words: commercial fisheries, recreational fisheries, conflicts, predator-prey, multiple use, optimal population levels.

Boyle, K.J. and R.C. Bishop. 1987. Valuing wildlife in benefit-cost analyses: a case study involving endangered species. Water Resources Research 23(5):943-950.

Abstract: This paper is concerned with the identification of relevant values in benefit-cost analyses that may affect wildlife or its habitat. A conceptual framework for examining the total value of a wildlife resource is developed and applied to valuation of two endangered species in Wisconsin; bald eagles and striped shiners. The components of value for wildlife resources are first discussed, with emphasis on those particularly relevant to endangered species. There are three basic groupings of use values: consumptive use value (hunting, fishing, trapping), nonconsumptive use value (viewing wildlife), and indirect use values (reading about wildlife, watching television specials about wildlife). An individual may hold more than one of these values for a specific wildlife resource. A theoretical model of individual preferences is next proposed to examine the relationships among different values and to determine their relationship to total value. Contingent valuation methods are used to estimate values for bald eagles and striped shiners. Empirical results indicate that Wisconsin taxpayers place a significant aggregate monetary value on the preservation of these two endangered species. The authors conclude that to overlook values for wildlife that go beyond common use values may result in misleading policy decisions.

Valuation techniques such as the method described in this paper may be used to estimate publicly-held values for resources which do not pass through market channels. This policy area would include the development of a recreational fishery on a previously unexploited species, such as squawfish, carp, or suckers. If the objective were to greatly reduce or eradicate a species (e.g. northern squawfish) with a control fishery, the concept of intrinsic existence values would be important in the evaluation of economic benefits of the management action. However, since the northern squawfish control fishery is conceptualized in terms of sustained moderate exploitation (about 20%), the main values of interest are the use values. If the total valuation concept were used for an economic analysis of the Columbia River fishery resources, it would probably tip the scales further in favor of managing for enhancement of salmonid species by reducing squawfish populations, since several salmonid stocks have been depleted or eliminated.

Keywords: wildlife, valuation, consumptive use value, nonconsumptive use value, indirect use value, preservation.

Cauvin, D. 1980. The valuation of recreational fisheries. Canadian Journal of Fisheries and Aquatic Sciences 37:1321-1327.

Abstract: At present, recreational fisheries are generally considered a non-priced (free) resource, based on the proposition that natural resources are a public heritage from which no member of society should be excluded. The validity of recreational fishing valuation techniques (expenditures, travel cost, value added, and willingness to pay methods) are questionable, and are poor substitutes for a price system. The author argues a need to adopt a pricing system to value recreational resources in order that equitable allocation decisions might be made, and that government management programs should be accountable for their allocation of resources. The major reason for not always pricing recreational use of fishery resources is that the costs of fee collection and enforcement may exceed benefits. Conventional wisdom suggests that the multifaceted nature of the recreational fishing opportunity makes rational pricing of recreational fishing very difficult, and perhaps impossible.

Recreational fisheries on northern squawfish in the Columbia River are negligible; the present recreational value of this resource may be considered zero. It is doubtful that anyone would pay for the opportunity to fish for squawfish under present conditions without additional incentives and organized promotion. However, since enjoyment of the fishing experience is generally considered of greater value than the food value of the fish caught, it is feasible that a recreational fishery could be developed on this resource. The recreational value of fishing for squawfish may be enhanced if the participants had a sense that they were benefitting the salmon fisheries by reducing predation.

Key Words: recreational fisheries, price system, valuation, multidimensional character of recreational fishing.

Charbonneau, J.J. and M.J. Hay. 1978. Determinants and economic values of hunting and fishing. Transactions of the North American Wildlife Conference 43:391-403.

Abstract: Better methods of monetary valuation of recreational hunting and fishing are needed foe enhancing decisions related to the costs and benefits of fish and wildlife and their habitat compared to alternative uses of land such as industrial and agricultural development. The purpose of this paper is to summarize several studies based on data collected by the 1975 National Survey

on Hunting, Fishing, Wildlife, and Associated Recreation, conducted by the U.S. Fish and Wildlife Service. Economists usually agree that consumer surplus is the appropriate measure of benefits which sportsmen derive from hunting and fishing that are attributable to the fish and wildlife resource. Consumer surplus is the amount an individual would pay to hunt or fish, above his or her actual expenses. Two approaches to estimating consumer surplus are discussed: 1) a direct question, willingness to pay method, and 2) an indirect method that derives value estimates from individuals' expenditures. Methods were applied to an example related to waterfowl hunting. Forecasting equations, when combined with estimates of economic values of hunting and fishing, can provide better information for assessing management alternatives.

This article discusses methods which are used for the valuation of recreational hunting and fishing. At present there is no appreciable recreational fishery on northern squawfish on the Columbia River. Predicting the monetary value of a recreational fishery on squawfish is beyond the scope of the current research project, and the data necessary for making such an estimate are lacking. If a recreational fishery were developed, it would be important to evaluate the fishery and collect the data needed for economic analyses of this type.

Keywords: fishing, hunting, recreation, valuation, consumer surplus, willingness to pay, expenditures.

Copes, P. and J.L. Knetch. 1981. Recreational fisheries analysis: management modes and benefit implications. Canadian Journal of Fisheries and Aquatic Sciences 38: 559-570.

Abstract: The purpose of this paper is to extend the theoretical analysis of recreational fisheries economics in order to integrate recreational and commercial fisheries management. The development of a common analytical base for recreational and commercial fisheries is essential if rational policy decisions are to be made on management of fish stocks which are jointly exploited by the two types of fisheries. The economics of commercial fisheries has generally been analyzed in terms of fundamental bioeconomic relations between sustainable yields and levels of fishing effort. In contrast, recreational fisheries have been analyzed as demand of consumers for opportunities to fish as a recreational pursuit--including intangibles related to the quality of the fishing experience. The common criteria for examining optimum utilization of the resource is the magnitude of benefits generated. One common denominator, to relate commercial and recreational fisheries, is the number and size of fish taken. In order to link commercial and recreational theory, the complex relation between the value of sport fishing enjoyment and the amount of fish taken must be determined. A major difference in the economics of the two types of fisheries is that commercial fish products are directly priced to the consumer, while sport fishing opportunities are provided free. The non-market nature of recreational fishing makes its valuation more difficult; but conceptually, the economic value of a product (fish) or service, (sport fishing opportunity) is the same--what people are willing to give up to obtain it.

In the case of the development of fisheries on Columbia River northern squawfish, managers under ordinary circumstances would assess commercial versus recreational fisheries in terms of their relative benefits to society. However, since the main benefit to society may be the enhancement of salmonid fisheries, this direct comparison of benefits is not as relevant to the overall management strategy. Instead, the two types of fisheries would be compared in terms of the relative cost and effectiveness of a bounty system applied to either a commercial (subsidized) fishery or a recreational (tournament) fishery to achieve a desired measurable level of exploitation of the squawfish population. Initially, the benefits of the fishery products would just help defray the costs of developing and subsidizing the fishery. In the long run, however, economics are important because the self-sustainability of the fishery in the absence of bounty incentives will probably determine the effectiveness of this management measure as a salmonid enhancement technique.

Keywords: recreational fisheries, commercial fisheries, joint exploitation, valuation, optimum utilization.

Crutchfield, J. 1965. Can we put an economic value on fish and wildlife? Colorado Outdoors 14(2):1-5.

Abstract: Water and land utilization are increasingly subject to more sophisticated techniques of evaluation and long-range planning. As those plans involve fish and wildlife decisions that are for practical purposes irreversible, economic techniques that fall within the confines of accepted practices of other water uses are essential. Valuation of fish and wildlife has been made more difficult by the insistence of many groups that hunting and fishing must be available at no cost. In the absence of a market, simulation studies are effective for economic valuation of fish and wildlife. Although conceptually correct, simulation studies are expensive. The author recommends that more intensive economic analysis be used as a basis for investment in fish and wildlife.

Valuation questions apply directly to the assessment of fishery development feasibility of squawfish. The trade-off between squawfish capture and salmonid predation implies a positive economic value--measured in terms of surviving juvenile salmon--to the harvest of squawfish. Whether the value of squawfish if a net positive value depends on the costs of harvest relative to returns from squawfish use and to the value of surviving salmon.

Keywords: economic valuation, fish, wildlife, investment.

Hannesson, R. 1983. Optimal harvesting of ecologically interdependent fish species. Working paper, Institute of Economics, University of Bergen, Norway.

Abstract: This paper considers the optimal exploitation of a two species predator-prey system. Due to the density-dependence of ecological efficiency, both species should be harvested simultaneously over a range of relative prices. Beyond the limits of this price range, either the prey species should be utilized indirectly by harvesting the predator, or the predator should be eliminated in order to maximize the prey yield. Certain results from single species fishery models are shown not to apply to multispecies models. These are: 1) optimal regulation of a free access fishery may call for subsidizing instead of taring the harvest of predator species; 2) increasing the discount rate may, at “moderate” levels, imply that the optimal standing stock of biomass increases instead of decreasing; 3) a rising price or a falling cost per unit of effort of a species may raise and not lower the optimal standing stock of that species.

The modeling effort reported in this paper has direct implications for the development of a fishery on northern squawfish. Choices between yield of predator and prey, as described in this paper, depend critically on relative values of the two species. These are the types of management choices that will be made for squawfish-salmon interactions and the fishery on each species.

Keywords: predator-prey, optimal exploitation, relative prices, management techniques.

Higgs, E.S. 1987. Changing value perspectives in natural resource allocation: from market to ecosystem. Transactions of the American Fisheries Society 116:525-531.

Abstract: Traditional approaches to natural resource allocation--deciding who gets what--have been based on economic considerations. The author argues that it is no longer adequate to simply apply market-driven criteria to questions of resource allocation. Recently the values underlying resource allocation have shifted to a more “moral” position based on heightened concern for the total environment. An ecosystem approach to allocation is advocated in which policy makers, resource users, and society decide on the desired future resource condition before deciding on the means of allocation. This approach brings values to the forefront of the decision process. However, mechanisms for instituting held values in the allocation process are not well-developed.

Development of a fishery on northern squawfish in the Columbia River will require the same type of “ecosystem” approach described in this paper. Because the procedures for accomplishing this are not well-developed, fishery development of squawfish would provide a good laboratory for the experimentation with different techniques to achieve equitable allocation.

Keywords: resources, allocation, values, ecosystem.

Knetsch, J.L. 1963. Outdoor recreation demands and benefits. Land Economics 39:387-396.

Abstract: This author discusses the difficulty with assigning values to resources used for recreation. Public agencies would like to provide a level of recreational resources commensurate with public preference but must make decisions in the absence of prices, the usual expression of value. Other means must be found of measuring consumer willingness to pay for recreation. This article focuses on travel costs and other costs as proxies for market value. In addition, income, site congestion and recreational alternatives are also factors in the demand for recreation. It is also difficult to fully account for benefits received by recreational users, because many recreational benefits are nonmaterial.

The types of analytical difficulties in recreational valuation that are described in this article will be factors in the assessment of a fishery on northern squawfish on the Columbia River. The decision to allocate the fishery to commercial or recreational users or to a combination of the two will be made more difficult without clearly defined values for recreational use.

Keywords: recreational resources, demand, benefits.

Martin, L.R.G. 1987. Economic impact analysis of a sport fishery on Lake Ontario: an appraisal of method. Transactions of the American Fisheries Society 116:461-468.

Abstract: A Keynesian-type economic impact analysis (EIA) was applied to the sport fishery in the Bay of Quinte, Lake Ontario in 1985 and 1985. EIA measures the direct, indirect, and induced consequences of resource development to a region, but does not assign an explicit value to the fishery resource. It is one facet of socio-economic impact assessment which can be used to forecast the social and economic consequences of resource development projects, thus providing managers and policy makers with valuable information for making decisions. EIA enables fishery managers to relate management decisions which cause a change in sportfishing activity to the effect on the regional economy in terms of sales, incomes, and jobs. An angler survey was conducted to collect detailed socioeconomic data. The methodology is outlined in the context of information needs of resource managers and planners. EIA can indicate the role of sportfishing in economic development and tourism, identify the relative contributions of angler groups, identify impacts on businesses, and suggest approaches to strengthen a region’s intersectoral linkages in order to maximize impact.

There is a potential need for a socioeconomic analysis of the effects of northern squawfish fishery development (commercial, bounty, or sport) on the regional economy. Such an analysis would have to be justified on the grounds that its results would help fishery managers and policy makers evaluate the relative merits of various predator control and salmonid enhancement measures. If this rationale were developed, then the appropriate methodology could be chosen on the basis of data requirements, cost, and desired accuracy and sophistication of results.

Keywords: freshwater fisheries, recreation, economic impact, EIA, economic development, tourism.

Martin, W.E., F.H. Bollman, and R.L. Gum. 1982. Economic value of the Lake Mead fishery. Fisheries 7(6):20-24.

Abstract: The economic value of Lake Mead, Colorado River as a hydroelectric power producer any source of water supply can be estimated from market prices; however, it is more difficult to estimate the value of its warm-water recreational fishery because a conventional market does not exist. The purpose of this paper is to estimate the value of the present fishery as input to the water management process. The Clawson-Hotelling method of developing a non-observed demand curve was used to estimate the value of nonmarket goods and services. Interviews with fishermen were used to gather data needed to develop the demand equation. First, a demand curve for the entire recreational experience is developed, next, a second-stage demand curve for the fishing activity itself is derived. Empirical data from individual fishermen are statistically fit to demand curves: these are summed to form aggregate demand curves for the fishery. Consumer surplus is the satisfaction a consumer receives from a commodity above the actual price paid. This measure may be interpreted as the total net value of the resource site to the fisherman for fishing. Since there is no entry fee for fishing at Lake Mead, the entire area under the demand curve for the site measures the quantity of consumer surplus generated.

At present there is a negligible recreational fishery for northern squawfish on the Columbia River. If squawfish derbies or tournaments were initiated to reduce predator numbers, however, the consumer surplus valuation technique may be a way to analyze recreational value derived by the public. This method may also be used to value existing sport fisheries on resident game fish (e.g. walleye) in comparison to existing sport and commercial fisheries on salmon, and potential commercial or bounty fisheries on northern squawfish.

Keywords: recreational fisheries, valuation, demand for fishing, consumer surplus.

Matlock, G.C. 1986. Estimating the direct market economic impact of sport angling for red drum in Texas. North American Journal of Fisheries Management 6:490-493.

Abstract: In this article the author develops a method for estimating the direct market economic impact of a sport fishery and applies this method to red drum (Sciaenops ocellatus) anglers in Texas. The economic value of recreationally caught fish can be measured in five ways: 1) market value of the catch, or direct expenditures to enter the fishery; 2) direct and multiplier effects of expenditures on local economies; 3) all direct and associated participation costs of the fishery; 4) the value placed on the fishing experience by the participant; 5) willingness to pay for the opportunity to participate. These approaches have problems, including difficulties in verification. As an alternative approach, the author estimated the direct market impact of the sport fishery for red drum in Texas by subtracting the market value of the fish from the total direct expenditures by red drum anglers. This approach assumes a commercial market for sport caught fish. The advantage of this approach is that it allows a direct comparison between sport and commercial fisheries in terms of direct economic impacts to determine how different allocations between sport and commercial fisheries would affect a region economically.

This approach would have direct bearing on allocation issues related to northern squawfish if opportunities for both commercial and recreational fisheries existed. If enough market demand exists for squawfish to make a commercial fishery economically feasible and if recreational demand also exists, managers may will face this type of allocation problem.

Keywords: recreational fishery, economic impact, allocation.

May, R., J. Beddington, C. Clark, S. Holt, R. Laws. 1979. Management of multispecies fisheries. Science 205(4403):267-277.

Abstract: Setting maximum sustained yield figures for individual species is an inadequate management strategy for multispecies systems. Models of krill-baleen whale interaction are used to illustrate the way multispecies fisheries respond to harvesting at various trophic levels. Economic aspects of harvesting multispecies fisheries are considered primarily for the purpose of improving acceptability and predictability of management regimes. Overexploitation of fisheries arises from the lack of strong property rights among fishermen to current and future fish. Uncertainty in biological systems also has important economic implications and creates conflicting responses by biologists and fishermen. Under uncertainty biologists will promote conservative management strategies but fishermen will discount future returns heavily and thus show an opposite response. Contingency plans to deal with unexpected changes are especially important for multispecies systems, although proper target levels for various species are difficult to determine. Multispecies systems often exhibit complex discontinuities in response to fishing or environmental change.

The authors reach several tentative conclusions about the management of multispecies systems. 1) For populations not subject to significant predation, MSY may be useful. 2) Ecosystem preservation requires that stock of a prey species not be reduced to levels affecting its own or other species productivity.
3) Time scales affecting population processes must be kept in mind.
4) Environmental stochasticity will cause population parameter estimates to fluctuate. 5) Multispecies systems have complex biological-economic-political interactions not found in single species systems.

Management of a squawfish fishery may well require techniques appropriate to the management of multispecies systems. Exploitation could occur simultaneously on stocks of squawfish, suckers, and carp. Further multispecies considerations will include those species which are not targeted in or caught by the squawfish/suckers/carp fishery but which interact with these species biologically.

Keywords: multispecies, management, species interactions, uncertainty.

Milliman, S.R., A.P. Grima, and C.J. Walters. 1987. Policy making within an adaptive management framework, with an application to lake trout (Salvelinus namaycush) management. Canadian Journal of Fisheries and Aquatic Management 44(Suppl. 2):425-430.

Abstract: In this paper the authors combine adaptive management techniques with concepts of natural resource economics to create a practical method for making policy choices in fisheries. The most appropriate fishery management action is that policy which is most likely to advance important socioeconomic objectives such as enhanced economic welfare, greater cultural opportunities, and species preservation. Uncertainties about the biological impact of various policies often impedes optimal policy choice. Lake trout (Salvelinus namaycush) rehabilitation in the Laurentian Great Lakes is used as an example. Uncertainties which impede the progress of lake trout rehabilitation are reviewed. These include uncertainty about recovery rates, sustainable exploitation rates, vulnerability to various sources of mortality, and lamprey predation. Next, a framework is proposed for developing a set of policy options which incorporate uncertainty, treating the uncertainties listed above as the focus for monitoring activities. Included in these options are "actively adaptive" policies which are experimentally designed to revive the lake trout fishery and yield data which may lessen uncertainties. The authors use basic concepts from natural resource economics such as net social and economic benefits, discount rates, time horizons, and expected value to outline how, in the presence of uncertainties, the policy which is most likely to maximize socioeconomic gains can be chosen from the various options. The strength of the adaptive management approach is its attempt to anticipate uncertainties and surprises and to incorporate new information in the process of fishery policy development.

Development of a fishery on northern squawfish will include an experimental phase in which different policy designs are applied. Adaptive management techniques seem to offer the best possibility for building a management strategy that incorporates both biological and economic uncertainties and the production of new information.

Keywords: fisheries policy, uncertainty, adaptive management.

Pearse, P.H. 1969. Toward a theory of multiple use: the case of recreation versus agriculture. Natural Resources Journal 9:562-575.

Abstract: The concept of "multiple use" has not been rigorously evaluated in terms of the critical issue of conflicting demands. The purpose of this article is to demonstrate the kind of information required to determine the socially optimum aggregate of conflicting uses of a natural resource, and clarify the criteria for establishing the optimum combined value. Production theory, based on biological concepts such as competition and carrying capacity, incorporates the relative value of alternative uses and provides reliable criteria for deciding the optimum combination of two or more competing uses of a fixed resource. Various kinds of investments in the resource can be evaluated in terms of increased total output and efficiency of alternative forms of enhancement. The assumed objective of multiple use has been to maximize the contribution of the resource to the welfare of the social group in whose interest it is managed. The highest value of a resource is derived by a combination of uses specified by the confrontation of a set of purely technical relationships with a set of economic ones. The biggest economic problem is establishing the value of resources which are provided free to users.

There are likely to be conflicting multiple uses of the northern squawfish resource if a Columbia River fishery for this species is developed. These will include sustaining the direct economic benefits of new fishery products, population control to reduce juvenile salmonid mortality, and achieving a balanced resident fish community, i.e., mediating compensatory mortality relationships with other predatory species.

Keywords: recreational fisheries, multiple use, conflict, production theory, investment evaluation, resource value.

Peyton, R.B. 1987. Mechanisms affecting public acceptance of resource management policies and strategies. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):306-312.

This article addresses the problem of management issues arising from Great Lakes rehabilitation efforts. Several issues require management: scientific and technological inadequacies, incomplete and/or conflicting public beliefs, and conflicting public values. This paper discusses the components of resource issues, the dynamics of public perception and response, and the role of public involvement in implementing management programs. A major component of resource issues is the adequacy and nature of science. Public education attempts have traditionally focused on the information products of science rather than the scientific process. This leaves the public without realistic expectations of the scientific basis for management. Another component of resource management issues is the conflicting values held by various groups. Additional factors with which resource managers must deal are the attitudes and behavior of the public. An important distinction exists between the goal of public acceptance of resource management and the process of public involvement. Public involvement may have a number of goals, including public acceptance. Public acceptance of a management program may be gained by several strategies, including public involvement. Resource agencies could better determine factors which determine public response to management programs if staff were trained to deal with the public dimensions of management. Especially important is the need for expertise to involve the public in resolving different value conflicts in issues. Resource managers must invest in long term programs to build rapport and credibility with the public, improve the public's understanding and participation in the management process, and gain a better understanding of the segments of the public affected by resource management.

The issues outlined in this paper are likely to be issues of importance in the development of a fishery on northern squawfish on the Columbia River. A key issue to be kept in mind during the fisherydevelopment phase is public perception of the management process. Public involvement in the design and implementation of policy for a new fishery should contribute substantially to public acceptance.

Keywords: resource management, conflicting values, beliefs, goals, public acceptance.

Pringle, J.D. 1985. The human factor in fishery resource management. Canadian Journal of Fisheries and Aquatic Sciences 42:389-392.

Abstract: Scientists and managers often assume fishermen oppose resource management when fishermen disregard a management plan developed without consultation or in an unclear manner. This paper argues that resource manager-fishermen relations are a critical, but often ignored, variable in the resource management equation. To permit good science to become good management, scientists, resource managers and fishermen must communicate effectively. Experience suggests that scientists and managers rarely look at the system of fishery resource management from the fisherman's perspective. The bulk of the regulatory decisions have been made by non-fishermen and in spite of regulations, many of our stocks have not been well-managed. Two case studies of fishery management are provided--one an example of successful cooperative government/ fishermen management and a second, contrasting example of unsuccessful management designed without fisherman input. The author concludes with an appeal to scientists and fishery managers to look at government's performance in resource management from the perspective of fishermen, to approach management with the operating assumption that fishermen care for their resource, and that industry and government cooperation in management may be formalized.

This paper identifies fisherman involvement as a key factor in the success of fishery management. Development of a fishery on northern squawfish is likely to proceed more smoothly if fishermen are involved from the beginning in the design and formulation of regulations.

Keywords: resource management, fishermen, consultation, communication.

Propst, D.B. and D.G. Gavrilis. 1987. Role of economic impact assessment procedures in recreational fisheries management, Transactions of the American Fisheries Society 116:450-460.

Abstract: Economic impact assessment (EIA) methodologies are analytical tools used to expose regional and interregional structures, to explain regional growth, and to help resource decision makers describe the effects of various policies and investments. At the federal level, benefit-cost analysis is used as a measure of efficiency of a government project in terms of the direct value of goods and services. The EIA is a value-free description of an economy at one point in time and is concerned primarily with the effects of total consumer expenditure. The EIA was developed as a descriptive method, but it can incorporate multipliers in order to achieve predictive capabilities. In recreational fisheries, typical "ratio multipliers" should not be applied to consumer spending for computation of total impacts; instead, a Keynesian relationship, which expresses additional impacts per unit of consumer spending, should be used. The hybrid data input-output model can satisfy the widest range of fisheries information needs. Theoretical and conceptual model development generally is more advanced than the empirical data base. At present, high quality data for the EIA of investment in fishery resources does not exist.

The EIA may be a useful method to evaluate the effect on the regional economy of the development of a commercial, bounty, or recreational fishery on northern squawfish. Perhaps the most important benefit derived from such a fishery would be the enhancement of salmonid populations. It would be difficult to quantify the incremental benefit of increased salmonid production derived from a northern squawfish removal fishery because of the concurrent interactions of a complex of salmonid enhancement measures targeted at a variety of detrimental factors, coupled with the inherent variability of the system. The foresight of gathering economic data within the framework of an analytical tool such as the EL4 may facilitate the development of a comprehensive control fishery evaluation program in the future.

Keywords: recreational fisheries, management, economic impact assessment, data quality.

Regier, H.A. and A.P. Grima. 1985. Fishery resource allocation: an exploratory essay. Canadian Journal of Fisheries and Aquatic Science 42:845-859.

Abstract: The authors explore several approaches to the problem of allocation of fishery resources. Interest is now growing in allocation because in most industrialized countries the complex of direct and indirect uses of ecosystems has led to environmental degradation and an increasing number of interactions among the effects of different user groups. Allocation and reallocation of rights to aquatic resources often occurs in a haphazard or covert way which is divisive and unjust to some user groups. This article addresses the problem of how to reduce the improprieties of allocations and at the same time enhance good husbandry to prevent environmental degradation. The authors propose a series

of guidelines which are designed to improve the allocation process. A number of societal means to the allocation of rights are identified, including markets, legal tribunals, administrative tribunals, and community negotiations. There is a need for a clearer specification of rights to a fishery as well as a need for improvements in the means by which those rights are allocated.

Allocation rights to northern squawfish and its associated species will need to be clearly specified if a fishery is developed. The guidelines presented in this paper will be helpful in building an allocation scheme that recognizes the rights of various interest groups and is therefore less likely to be divisive.

Keywords: fisheries, resource allocation, formal rights, informal rights, environmental degradation, husbandry.

Rettig, R.B. 1987. Bioeconomic models: do they really help fishery managers? Transactions of the American Fisheries Society 116:405-411.

Abstract: Pacific Northwest salmon managers have dealt with management crises for more than a century. Management responsibilities have increased in recent years with new user groups, new management regimes, increased enhancement and mitigation efforts, and concern about the depletion of wild stocks. Planning and policy decisions are increasingly difficult. In response to progressively more complex management issues, computer models of increasing sophistication are being used. Managers need to know whether such models can assist them with two major categories of decisions: 1) How should a long-range fishery goal be modified to address short-run economic concerns, such as high unemployment levels? 2) What criteria should be used to allocate a limited quota among competing users? This author argues that social scientists should be aware that types of knowledge other than "scientific" knowledge will be incorporated into the policy process. A great deal of "ordinary" knowledge will be brought to the policy process through the inclusion of public advisory bodies. This ordinary knowledge will be combined with scientific knowledge by managers. This has implications for the way social scientists construct bioeconomic models: managers should be incorporated in model building from the development stages onward, rather than consulted at the end of the modeling exercise.

Development of a bioeconomic model of the fishery on northern squawfish or of northern squawfish--salmon fishery interactions will be a likely analytical outcome of current fishery development potential. Such an exercise will require that managers be involved in model construction from the beginning if the resultant model is to be relevant to managers' needs.

Keywords: bioeconomic models, fishery management, scientific knowledge, ordinary knowledge.

Schlick, R.O. 1978. Management for walleye or sauger, South Basin, Lake Winnipeg. Pages 266-269 in Selected coolwater fishes of North America, R.L. Kendall, ed., American Fisheries Society Special Publication No. 11.

Abstract: Walleye and sauger are the main species comprising the commercial fishery in the South Basin of Lake Winnipeg, Manitoba. Gill net mesh size restrictions can be used to manage in favor of walleye (large mesh) or for the smaller sauger (small mesh). The more liberal 76mm gill net mesh would be more economically favorable for fishermen because it would increase the catches, but it would probably decrease the population of walleye because fewer numbers would reach reproductive size. Thus the 108mm mesh restriction would favor the larger walleye. Water transparency is an important environmental variable affecting the relative dominance of the two species--clear water generally favors walleye.

Consideration of size-selective fishing gear (such as gill net mesh size restrictions) would be an important economic consideration in terms of optimum size and numbers of northern squawfish commercially harvested in the Columbia River, and also in terms of management of other food and game fish such as walleye.

Keywords: freshwater fisheries, management, gear restrictions, optimum mesh size, economic tradeoffs.

Sharif, M. 1986. The concept and measurement of subsistence: a survey of the literature. World Development 14(5):555-577.

Abstract: Subsistence is a widely used concept in theoretical literature, empirical literature, and in the policy arena. Despite widespread use of the concept, its precise meaning is not well-understood. The author first examines the manner in which the concept of subsistence is used to refer to production and consumption activities. The concept of subsistence used in different economic theories is an absolute minimum standard of productive living, not just survival. In addition to survival needs, subsistence includes needs of physical and mental efficiency. Income level is one measure used to characterize the standard of subsistence. The author identifies three methods of determining subsistence-level living and finds the two most commonly used methods--social (direct observation of a society's minimum standard) and scientific (minimum mental or physiological requirements)--to be arbitrary. The third method--the behavioral method--identifies subsistence by observing the behavior of people at the lower level of the income distribution. The author concludes that the behavioral approach is the method which offers the most promising direction for measurement.

The regulatory review process and the policy development phase of the squawfish feasibility project could well identify a potential squawfish fishery as a tribal fishery. If this identification is the outcome the possibility of subsistence fishing may arise. This article will help to clarify the meaning of that concept.

Keywords: subsistence, survival, income, social minimum, behavior.

Talhelm, D.R. 1979. Fisheries dollars and cents. Water Spectrum 11:8-16.

Abstract: The commercial fishery in the Great Lakes was historically of great social and economic importance to the region, but now the sport fishing industry had much greater importance. Economists have estimated that the net social value of Michigan's Great Lakes sport fishery is $250 million compared to $2 million for the commercial fishery. The economic impacts of the two fisheries are about $250 million sport and $20 million commercial. Fisheries have several kinds of values to society, and the purpose of fisheries management is to maximize the aggregate of these values. The concepts of economic rent and angling quality and demand are methods to determine sport fishing values. Bioeconomic simulation models incorporating demand equations can be used to quantify the economic efficiency of salmon enhancement projects to sport fisheries and the relative values of commercial fisheries. The effect of fisheries on local and regional economies is discussed in the context of fishery management decisions, equitable distribution of income among fishery factions, and preserving "ways of life" such as commercial fishing villages. Although sport fishery values are greater than commercial values, the greatest aggregate value is derived by having both, especially when fish species used by the commercial fishery are not game fish. A detailed economic analysis of management alternatives can quantify values and trade-offs and thus help fishery managers make decisions. However, many potential benefits and detriments are not adequately known or quantified.

At present, both sport and commercial fisheries on northern squawfish in the Columbia River are negligible. When and if these fisheries develop, it will be important to quantify their relative values in the context of a bioeconomic model. The effect of the fishery in reducing northern squawfish abundance and the resultant benefits to the salmon fishery would be an important component of such a model.

Keywords: Great Lakes, commercial fisheries, recreational fisheries, evaluation of enhancement projects, trade-offs.

Tschirhart, J. and T.D. Crocker. 1987. Economic valuation of ecosystems. Transactions of the American Fisheries Society 116:469-478.

Abstract: This paper demonstrates one way in which an empirically meaningful link between economies and ecosystems might be developed. The natural ecosystem is characterized by inputs, physiological functions, and energy contents of biomass. Humans intervene in the ecosystem by farming, cutting timber, or fishing and thereby directly or indirectly affect all of these features. A model is developed in which human behavior alters the detailed structure of the ecosystem, which in turn alters human behavior. A proposed methodology is presented for valuing ecosystem components which have no direct use value for humans.

This article is relevant to understanding the impacts of a control fishery on northern squawfish, particularly in terms of the multispecies linkages that exist between squawfish and salmonids, suckers, and carp. It has a further bearing on the assessment of the value of an ecosystem component without any current economic value, a characterization which fits squawfish at this time.

Keywords: economics, ecosystems, interaction, valuation.

Vanderpool, C.K. 1987. Social impact assessment and fisheries. Transactions of the American Fisheries Society 116:479-485.

Abstract: Although social impact assessment methodologies have been developed and applied in other areas of natural resource management, particularly forestry and water resources, they have not been applied in fisheries. Social impact assessments contribute to the process of policy design and management by providing information on the costs and benefits of proposed conservation and management plans. One requirement of a social impact assessment is the construction of a social and cultural data base. Because social impact assessments have not been done in fisheries these data bases have not been built. Social and cultural data are useful to asses the distributional consequences of a particular fishery management plan. What is desirable in resource management is an integrated assessment and evaluation process which provides a coordinated system for determining the costs and benefits of policy implementation and project outcomes. Good social impact assessments in the fishery would require an understanding of the role of assessment in natural resource development as well as the development of good comparative data bases on social factors related to fishing.

The types of social and cultural data described in this article would be crucial to an understanding to the impact of fishery development on Columbia River northern squawfish. A social impact assessment would provide valuable information on the likely impact of a particular development approach or allocation scheme that might otherwise be ignored.

Keywords: fisheries, social impact assessment, social, cultural, allocation, fishery development.

Wilson, J. 1982. The economical management of multispecies fisheries. Land Economics 58(4):417-434.

Abstract: This paper is concerned with developing an economic analysis appropriate to the biological and social characteristics of variable multispecies systems. The paper is built on three fundamental ideas: 1) limitations of knowledge and uncontrolled variation in fisheries constrain the range of economically feasible management options; 2) social costs of rule making and enforcement are high in highly variable environments; 3) efficiency in variable environments is more closely related to adaptive individual learning behavior than

to input cost minimization. These ideas are developed in the context of an institutional theory about the growth of collective mechanisms for the solution of potentially degenerative social situations.

The accepted economic theory of fisheries is misleading in that it tends to direct analysis away from a consideration of many reasonable and economical non-property rights policy alternatives. Consideration of "complicating factors"--multiple species, variability, patchiness, search and information costs--tends to lead to the conclusion that the social costs of unregulated fishing are less than traditional economic theory would suggest. These complicating factors indicate higher social costs associated with attempts to regulate. These two effects tend to limit the range of economically feasible management options and appear to create a strong preference for very simple systems of management rules.

The management of a fishery on northern squawfish as a multispecies fishery would suggest an application for several of the ideas outlined in this paper. Marine fisheries offer many examples of multispecies fisheries that are managed as concurrent single-species systems, with the associated social costs. This paper points out some of the costs of attempting to "over manage," or fine-tune, a multispecies fishing system.

Keywords: multispecies fisheries, management, efficiency, adaptive learning, social costs.

Yarbrough, C.J. 1987. Using political theory in fisheries management. Transactions of the American Fisheries Society 116:532-536.

Abstract: This paper explores three areas of political theory and their implications for fishery management. First, democratic theory states that ultimate political power in a society is vested in the people. This includes a belief in local autonomy and a belief that public opinion has ethical status. Democratic theory confronts fishery managers with the need to respect the tradition of localism and generate public support for programs. Second, political value theory attempts to understand values held by the public. Core values held by the public are persistent. This means that managers must justify programs in terms of consistency with basic public values. Third, political structure theory looks at the influence of formal and informal government, economic, and social structures on the acceptance and success of public programs. Structure theory describes the limits of political action as well as the possibilities. This theory tells managers that the structure of existing governmental and economic institutions works against broad management initiatives, against taking an ecosystem approach to management. The author argues that political theory provides insight to fishery managers about what is possible as well as what is not possible.

This article offers insights into the process of fishery management, both in terms of pathologies in our existing management process and in terms of possibilities for change and limits to those possibilities. This is a helpful review of process that would provide guidance in the formation of new policy for fishery development.

Keywords:. resource management, political theory, democratic principles, values, institutional structure.

# APPENDIX B-2.

Preliminary Results of Tests for Contaminants in Northern Squawfish

1. FDA Foodstuff Action Levels for Selected Contaminants
2. Organic Contaminants
3. Heavy Metal Contaminants

B-2.1. FDA Foodstuff Action Levels for Selected Contaminants

Table B-5. FDA Foodstuff Action Levels for Selected Contaminants.

| | FDA Foodstuff Action Level (ppm) |
|---|---|
| **Chlorinated Pesticides and PCB's** | |
| alpha-BHC | 0.3* |
| beta-BHC | 0.3** |
| Lindane | 0.5 |
| Heptachlor | 0.3 |
| Heptachlor epoxide | 0.3 |
| Aldrin | 0.3*** |
| Dieldrin | |
| p,p' DDE | 5.0 |
| p,p' DDD | 5.0 |
| p,p' DDT | 5.0 |
| p,p' Methoxychlor | 5.0 |
| Chlordane | 0.3 |
| PCB Group 1 | 2.0 |
| PCB Group 2 | 2.0 |
| PCB Group 3 | 2:o |
| PCB Group 4 | 2.0 |
| PCB Group 5 | 2.0 |
| **Heavy Metals** | |
| Mercury | 1.0 |
| Arsenic | **** |
| Cadmium | **** |
| Chromium | **** |
| Copper | **** |
| Lead | **** |
| Zinc | **** |

* Level established for rabbit meat. No level established for fish.
** Level established for eggs. No level established for fish.
*** Level established for sum of Dieldrin and Aldrin values.
* * * * No FDA Action level established.

B-2.2. Preliminary Results of Tests for Organic Contaminants in Northern Squawfish.

PRELIMINARY report, results are NOT conclusive. Printed by

CASE NAME: 890371 JOHN DAY RESERVOIR
SUBMITTER: Vigg,Steve
FUND CODE: 3250 205J(5)- Nonpoint Source

| ITEM # | RESULT | UNITS | TEST |
|---|---|---|---|
| 001 Small Fish, Edible portion 05/03/89 | | | |
| | ATTACHed | | Chlorinated Pesticides in Tissues, fish Tissue |
| 002 Large Fish, Edible portion 05/03/89 | | | |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |
| 003 Small Fish, Liver 05/03/89 | | | |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |
| 001 Large Fish, Liver 05/03/89 | | | |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |

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JUN 16 1989
Water Quality Division
Dept. of Environmental Quality

Department of Environmental Quality
Laboratories and Applied Research
Organic Section

GC
CHLORINATED PESTICIDES AND PCBs
Complies with EPA NPDES Method 608 and
RCRA Method 8080

**Date:** I June 1999

Lab O: 898371
**Sample:** I-FISH
**Item #:** 1 59D

| Amount MG/KG | Parameter | CAS Registry Number |
|---|---|---|
| <0.003 | alpha-BHC | 319846 |
| <0.003 | beta-SHC | 319857 |
| ma83 | Lindane | 58899 |
| <0.003 | Heptachlor | 76448 |
| <0.003 | Aldrin | 309002 |
| <0.003 | Heptachlor epoxide | 1024573 |
| (0.003 | p,p' DDE | 72559 |
| <0.003 | Endrin | 72208 |
| <0.003 | p,p'DDD | 72548 |
| <0.003 | p,p'DDT | 50293 |
| <0.003 | p,p'Methoxychlor | 72435 |
| 0.011 | Dieldrin | 60571 |
| <0.003 | Chlordane | 57749 |
| <0.012 | PCB Group 1 | 11 104282 |
| <0.006 | PCB Group 2 | 11141165 |
| <0.003 | PCB Group 3 | 53469219 |
| <0.003 | PCB Group 4 | 11097691 |
| (8.803 | PCB Group 5 | 11096625 |
| ND | Total PCB | |

PCB Group I includes PCB 1221 and is calculated as 1221.
PCB Group 2 includes PCB 1232 and in s calculated as 1232.
PCB Group 3 includes PCS'S 1016, 1242 and 1248 and is calculated as *1242.*
PCB Group 4 includes PCB 1254 and is calculated as 1254.
PCB Group 5 includes PCB's 1260 and 1262 and is calculated as *1268.*

ND No PCB's observed above indicated detection limit.

Departaent o f Environaental Quality
Laboratories and Applied Research
Organic Section

PRELIMINARY

DATE:

GC
CHLCRINRTED PESTICIDES AND PCBs
Coaplies with EPA NFDES Method 603 and
RCRA Method 8080

Bate: 1 June 1989

Lab #: 890371
Saaple: 2-FISH
Iteo #: 2

590

| Amount MG/KG | Parameter | CA3 Registry Number |
|---|---|---|
| <0.303 | alpha-BHC | 319846 |
| <0.003 | beta-BHC | 319857 |
| <0.003 | Lindane | 588'19 |
| <0.003 | Heptachlor | 76448 |
| <0.003 | Aldrin | 309002 |
| <0.303 | Heptachlar epoxide | 1024573 |
| 0.073 | p,p' DDE | 72559 |
| <0.003 | Endrin | 72208 |
| 0.007 | p,p'DDD | 72548 |
| <0.003 | p,p'DDT | 50293 |
| <0.003 | p,p'Methoxychlor | 72435 |
| (8.803 | Dieldrin | 60571 |
| <0.003 | Chlordane | 57749 |
| a.012 | PCB Group 1 | 11104282 |
| <0.006 | PCB Group 2 | 11141165 |
| <0.003 | PCB Group 3 | 53469219 |
| 0.113 | PCB Group 4 | 11897691 |
| 0.041 | PCB Group 5 | 11096625 |
| 6.154 | Total PCB | |

PCB Group 1 includes PCB 1221 and is calculated as 1221.
PCB Group 2 includes PCB 1232 and in s calculated as 1232.
PCB Group 3 includes PCD'S 1016, 1242 and 1248 and is calculated as 1242.
PCB Group 4 includes PCD 1254 and is calculated as 1254.
PCB Group 5 includes PCB's 1260 and 1262 and is calculated as 1260.

ND No PCB's observed above indicated detection liait.

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Laboratories and Applied Research
Organic Section

PRELIMINARY

GC
CHLORINATED PESTICIDES AND PCBs
Complies with EPA NPDES Method 608 and
RCRA Method 8080

Date: 1 June 1989

Lib I: 890371
Sample: REDFISH
Item #: 3 550

| Amount MG/KG | Parameter | CAS Registry Number |
|---|---|---|
| <0.003 | alpha-BHC | 319846 |
| <0.003 | beta-BBC | 319857 |
| <0.003 | Lindane | 51899 |
| <0.003 | Heptacblor | 76440 |
| 8.03 | Aldrin | 389002 |
| <0.003 | Heptachlor epoxide | 1024573 |
| 0.765 | p,p' DDE | 72559 |
| (0.003 | Endrin | 72208 |
| 0.248 | p,p'DDD | 72548 |
| <0.003 | p,p'DDT | 50293 |
| 0.004 | p,p'Methoxychlor | 72435 |
| 0.037 | Dieldrin | 60571 |
| <0.003 | Chlordane | 57749 |
| <0.012 | PCB Group 1 | 11104262 |
| <0.006 | PC3 Group 2 | 11141165 |
| <0.003 | PCB Group 3 | 53469219 |
| <0.003 | PCB Group 4 | 11997691 |
| <0.003 | PCB Group 5 | 11096825 |
| ND | Total PCB | |

PCB Group 1 includes PCS 1221 and is calculated as 1221.
PCB Group 2 includes PCB 1232 and in s calculated as 1232.
PCB Group 3 includes PCB'S 1616, 1242 and 1248 and is calculated as 1242.
PCB Group 4 includes PCB 1254 and is calculated as 1254.
PC3 Group 5 includes PCB's 1260 and 1262 and is calculated as 1268.

NO No PCB's observed above indicated detection limit.

Departaent o f Environment'l Quality
Laboratories and Applied Research
Organic Section

PRELIMINARY
DATE:

GC
CHLORINATED PESTICIDES AND PCBs
Coaplies with EPA NPDES Method 608 and
RCRA Method 8080

Date: 1 June 1989

Lab #: 890371
Sample: BLUFISH 550
Item #: 4

| Aaount MG/KG | Paraaeter | CBS Registry Nuaber |
|---|---|---|
| <0.003 | alpha-BHC | 319846 |
| <0.003 | beta-BHC | 319857 |
| <0.003 | Lindane | 58899 |
| 0.33 | Heptachlor | 76448 |
| <0.003 | Aldrin | 309002 |
| (0.003 | Heptachlcr epoxide | 1024573 |
| 3.13 | p,p' DDE | 72559 |
| 0.74 | Endrin | 72208 |
| 0.99 | p,p'DDD | 72548 |
| (0.603 | p,p'DDT | 50293 |
| (6.603 | p,p'Methoxychlor | 72435 |
| <0.003 | Dieldrin | 60571 |
| <0.003 | Chlordane | 57749 |
| (8.012 | PCB Group 1 | 11104282 |
| (0.056 | PCB Group 2 | 11141165 |
| <0.003 | PCB Group 3 | 53469219 |
| (8.003 | PCS Group 4 | 11097691 |
| <0.003 | PC8 Group 5 | 11096625 |
| NO | Total PCB | |

PCB Group 1 includes PCB 122: and is calculated as 1221.
PCB Group 2 includes PCS 1232 and in s calculated as 1232.
PCB Group 3 includes PCB'S 1016, 1242 and 1248 and is calculated as 1242.
PCB Group 4 includes PCB 1254 and is calculated as 1254.
PCB Group 5 includes PCB's 1260 and 1262 and is calculated as 1260.

ND No PCS'; observed above indicated detection limit.

FATS / LIPIDS

PRELIMINARY
DATE:

| LAB # | ID # | FISH TYPE | ppm * | % * |
|---|---|---|---|---|
| 890371-3250 | 1-Fish | Squawfish | 12555 | 1.256 |
| | 2-Fish | Squawfish | 5180 | 0.518 |

* wet method
(wet weight basis)

B-2.3. Preliminary Results of Tests for Heavy Metal Contaminants in Northern Squawfish.

DEPARTMENT OF ENVIRONMENTAL QUALITY
Request for Analysis

Case No. 890371

Location/Site2 JOHN DAY RES.  Date Sampled: APRIL 27 - MAY 2  Date Received in Lab: 5/3/89

Collected by: STEVE VIGG  Fund Coder 3250  Date Reported: OCT 4 1989

Purpose:

Report Data to: HAFELE / FOSTER / VIGG
STEVE VIGG, 17330 S.E. EVELYN
CLACKAMAS, OR 97015

Comments:

| Item # | Sampling Point Description (include time) | Nutrients / Basic | DO / BOD | Metals / Organic | Misc. / Misc. | Test(s) Required |
|---|---|---|---|---|---|---|
| 1 | SMALL FISH EDIBLE PORTION | | | | 1 FSH | TISS XTISS. |
| 2 | LARGE FISH EDIBLE PORTION | | | | 2 FSH | |
| 3 | SMALL FISH LIVER | | | | RDFSH | |
| 4 | LARGE FISH LIVER | | | | DLFSH | |
| 5 | | | | | | |
| 6 | | | | | | |

Laboratory Comments:

Contact Sample Tracker for proper sampling **containers** and preservation procedure. **(503) 229-5983**

275

Predator-Prey Projec
ODFW

| Fish # | Date | station | Size | !-G-k len (mm) | Wet (g) | Gonad | Liver | Flesh | Whole |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Mar 02 | 161-130 | I-at-se | 441 | 1355 | x | X | X | |
| 2 | May 02 | 161-050 | Small | 324 | 510 | x | X | X | |
| 3 | April 27 | 161-050 | Small | 2.39 | 160 | | | | X |
| 4 | April 27 | 161-050 | Small | 323 | 415 | | | | X |
| 5 | April 27 | 161-050 | Small | 332 | 490 | | | | X |
| 6 | May 02 | 161-130 | Small | 357 | 690 | | | | X |
| 7 | May 02 | 161-050 | Small | 352 | 620 | | | | X |
| 8 | Mar 02 | 161-050 | Large | 4 4 3 | 1630 | | | | X |
| 9 | May 02 | 161-050 | Large | 473 | 1840 | | | | X |
| 10 | May 02 | 161-050 | Large | 431 | 1260 | | | | X |
| 11 | May 02 | 161-130 | Large | 452 | 1310 | | | | X |
| 12 | Mar 02 | 161-050 | Large | 432 | 1090 | | | | X |

276

Station 161-130 is in the John Day Reservoir on the Oregon shore below McNary Dam East of the Umatilla River.

Station 161-050 is in the John DaY Reservoir on the Oregon shore below McNary Dam East of the power lines next to social security pond.

*DEPARTMENT OF ENVIRONMENTAL QUALITY LABORATORIES*
Analytical Records Report

WEDNESdAY OCTOBER 4th, 1989

CASE NAME: 890371 JOHN DAY RESERVOIR
SUBMITTER: Gates, Richard f. COLLECTOR: Vigg, Steve
FUND CODE: 3250 205J(5)- Nonpoint Source

| ITEM # | RESULT | UNITS | TEST |
|---|---|---|---|
| 001 Small Fish, Edible portion 05/03/89 | | | |
| | 0.98 | mg/Kg dry | Mercury, Fish Tissue |
| | <0.15 | mg/Kg dry | Arsenic, Fish Tissue |
| | <0.04 | mg/Kg dry | Cadmium, Fish Tissue |
| | <0.15 | my/Kg dry | Chromium, Fish Tissue |
| | 1.4 | mg/Kg dry | Copper. Fish Tissue |
| | <0.15 | mg/Kg dry | Lead, Fish Tissue |
| | 23.3 | % | % SOLIDS, Fish Tissue |
| | 22 | mg/Kg dry | Zinc, Fish Tissue |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |
| 002 Large Fish, Edible portion 05/03/89 | | | |
| | 3.20 | mg/Kg dry | Mercury, Fish Tissue |
| | <0.15 | mg/Kg dry | Arsenic, Fish Tissue |
| | <0.04 | mg/Kg dry | Cadmium, Fish Tissue |
| | <0.15 | mg/Kg dry | Chromium, Fish Tissue |
| | 1.2 | mg/Kg dry | Copper. Fish Tissue |
| | <0.15 | mg/Kg dry | Lead, Fish Tissue |
| | 23.0 | % | % SOLIDS, Fish Tissue |
| | 19 | mg/Kg dry | Zinc, Fish Tissue |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |
| 003 Small Fish, Liver 05/03/89 | | | |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |
| on4 Large Fish, Liver 05/03/89 | | | |
| | ATTACHed | | Chlorinated Pesticides in Tissues, Fish Tissue |

REPORT C

# EVALUATION OF HARVESTING TECHNOLOGY FOR POTENTIAL NORTHERN SQUJAWFISH COMMERCIAL FISHERIES IN COLUMBIA RIVER RESERVOIRS

Prepared by

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School of Fisheries, WH-10
University of Washington
Seattle, Washington 98195

CONTENTS

## ACKNOWLEDGMENTS

We thank the operators of the Umatilla marina for providing us boat and net pen moorage and other facilities and services at very reasonable rates. We thank Mr. Brad Eby and others of the U.S. Army Corps of Engineers at McNary Dam for providing us smolt collector mortalities for bait. Thanks also to Mr. Paul Wagner, Washington Department of Fisheries biologist at McNary Dam for help in smolt mortality collections.

## ABSTRACT

After literature review and discussion with knowledgeable experts, we chose four small-boat gear types to test in the field for their applicability to commercial harvest of northern squawfish, ***Ptychocheilus oregonensis*,** in Columbia River reservoirs: Purse seine, long line, gillnet, and baited pot.

From April to August 1989, we tested these gears in five areas of the John Day reservoir. Limited purse-seining with a 350X2.5 deep seine was very ineffectual except in the McNary Dam spillway where catches averaged five northern squawfish per set; northern squawfish composed 44% of the purse-seine catches (in numbers) of all species. Baited pots and floating gillnets (set and drift) were relatively ineffectual. A total of 167 one-plus hour sets of stationary, sunken gillnets yielded 122 northern squawfish. The nets were of variable mesh and measured 150x10 ft. Northern squawfish composed 14% of the sunken gillnet catches of all species. Longlining with monofilament groundline, 3/0 stainless hooks and salmonid smolts for bait was the most effective method. A total of 525 northern squawfish was caught on 115 sets of 25-150 baited hooks. Catches of one northern squawfish per 4 or 5 hooks set were the best rates achieved; these were made near McNary Dam. Northern squawfish composed 72% of the catches of all species. White sturgeon, ***Acipenser transmontanus*,** and channel catfish, ***Ictalurus punctatus*,** were caught frequently on longlines and were usually alive and viable at release.

## INTRODUCTION

Northern squawfish, *Ptychocheilus oregonensis*, in the Columbia River are of limited recreational use and currently of no commercial value. They are, however, the major predator of outmigrating salmon in the John Day reservoir and probably throughout the Columbia River; research in the John Day reservoir demonstrated that northern squawfish consume a sufficiently high proportion of the salmonid outmigrants to probably cause significant reduction in the numbers of adult salmon and steelhead (Poe and Rieman 1988). Mode1 studies indicated that a sustained exploitation rate of 10-20% annually in the John Day reservoir would reduce the population and average size of northern squawfish sufficiently to cause a major reduction in salmonid losses (Rieman and Beamesderfer 1988). A variety of fishing methods could be employed to achieve this level of harvest. Among them, one or several should be found which (1) would not incidentally kill valued fish such as salmonids, sturgeon, catfish, bass, or walleye; (2) could be inexpensively employed by commercial fishermen using the type of small vessels already in use for salmon, sturgeon, and shad fishing on the Columbia; and (3) would have sufficiently high catch rates on northern squawfish to yield an annual exploitation rate of approximately 20%.

Obviously item (3) will not happen unless there is sufficient economic return from the catch. This can occur from either of two sources: (1) Development of commercial markets for northern squawfish, or (2) establishment of a bounty or subsidy by a public agency. Establishing potential commercial outlets and setting a correct level of bounty are the objectives of a sister research project by Oregon State University (OSU) ("Economic Feasibility of Commercial and/or Bounty Fisheries for Northern Squawfish").

The goal of the multiple-agency predator-prey research programs on the Columbia River, of which the Harvest Technology project is one phase, is to increase adult salmonid returns by reducing in-river predation on outmigrants. One aspect of active management of predation-caused losses of juvenile salmonids would be the development of a fishery on northern squawfish in order to reduce their numbers. The goal of the Harvest Technology evaluation (Addendum to Statement of Work, Project 82-012) is to provide further detail to Objective 3, Task 3.2, Activity 3.213--specifically, the component dealing with harvest technology. The specific objectives are to:

(1) Evaluate commercial harvesting technology of various fishing methodologies for northern squawfish in Columbia River reservoirs.

(2) Field test the effectiveness of identified commercial harvesting systems, i.e., fishing methods, holding facilities, and transportation.

(3) Integrate the "Harvesting Technology" research with other components of the study, i.e., coordination to ensure research and data collection are designed to support the "Economic Feasibility" study.

(4) Assess potential for incidental catch mortality of valued species for each of the gear types tested for use in northern squawfish harvesting.

The "Harvesting Technology" project period is 1 February 1989 - 31 March 1990. The present report covers activities concerned with literature search, gear selection, gear design and construction, field station operation, field testing of gear, data acquisition, and northern squawfish holding and transportation through 1 September 1989. Intensive field testing will continue through November 1989 with spot testing thereafter as weather and fishing success dictate. Further analysis of field data through 1 September 1989, as well as field data obtained thereafter will be presented in the final report to be completed by 31 March 1990.

The project began with a two-month (March-April) information search which included literature review and personal contacts with biologists, fishermen, and fishing gear manufacturers who had experience with commercial or control fisheries on non-game freshwater species (Appendix C-l). Based on this information, gear types were selected for field testing. Gear equipment was purchased, and two Boston Whalers, open outboard-powered boats, were appropriately outfitted. One was a 22-footer with a 200-hp engine provided by Oregon Department of Fish and Wildlife to our project; the other was a 20-footer with a 165-hp engine chartered from the University of Washington. A field station which included housing, storage and working facilities was leased in Umatilla, OR.

Preliminary fishing activities commenced in April 1989. For the period 15 May-12 August, a pre-set spatial/temporal pattern of fishing and biological sampling in the John Day reservoir was followed, except for minor modifications required by weather and other unforeseen events.

During our project we evaluated only commercial fishing gear types as control alternatives. Other techniques to reduce squawfish predation on salmonids have been researched and could be utilized in conjunction with a commercial fishery (Jeppson and Platts 1959; LeMier and Mathews 1962; Hamilton et al. 1970; Poe et al. 1988).

A commercial fishery has several advantages. It is well-known that virtually any stock of fish can be reduced substantially by commercial fishing if economic incentives are high. A commercial fishery could use an existing pool of skilled manpower and boats at times when not alternatively employed. A commercial fishery might be easier to regulate and evaluate than a sport fishery, which is another control alternative, because fewer but more efficient individuals would be involved with the former. If a market can be developed for northern squawfish, there is potential for economically self-sustaining control. Additionally, a potential resource would then be utilized.

If a commercial fishery is to develop, potential fishermen need to know expected CPUE by location and season, investment and operation costs of suitable gear and equipment, and various operational constraints such as weather and water conditions and availability of ancillary facilities like moorage and launching sites. Our project is intended to provide such information. Additionally, fishermen need to know expected prices, product forms, and handling and delivery requirements. Such data are products of the sister study by OSU.

The fishery management agencies have several concerns to face in developing a commercial northern squawfish fishery. How can squawfish be harvested with least impact on other species? Can squawfish be commercially harvested in a manner that does not interfere significantly with other users of Columbia River water resources? Does squawfish harvesting effectively reduce salmonid predation? And finally, are there any adverse ecological effects with reduction of squawfish populations? Informational needs for certain aspects of these questions are also to be provided by our "Harvest Technology" project.

## METHODS

### Selection of Fishing Gear for Testing

Our main criteria for gear selection were (1) that it be adaptable to commercial vessels of the sizes and types generally used in the Columbia River and adjacent regions, and (2) that it be suitable to the physical environment of Columbia River reservoirs. Columbia River fishing vessels tend to be less than 30', are outboard or inboard/outboard powered, and may be open (no cabin). We therefore considered the following gear types as potential candidates for field testing: Purse seine, baited longlines, beach seine, baited pots, set gillnet, drift gillnet, and trap net.

Table C-l summarizes our selection process. We developed a subjective scoring system (l-3 points), ranking each gear type according to the 10 criteria shown. A high-ranking score indicates relatively high degree of suitability.

Purse seining is relatively untested, particularly away from dam areas. It can be done from small boats, but usually two boats are needed. Specific modifications must be made to a boat, but these might not be too costly if a boat already had a net reel and hydraulic system. Product quality should be excellent since the fish are alive at capture; live capture also allows the potential of releasing other species unharmed. Purse seining would be difficult in high winds which are common in Columbia River reservoirs. Two or three crewmen are required, but seining, as opposed to stationary gear types, would not have gear-tending requirements, nor would conflict due to entanglement with sport fishermen or other vessels be a likely problem. Purse seining is limited to depths greater than the net depth.

Baited long-lines have not been previously tested for squawfish and are easily and cheaply adaptable to boats of any size capable of handling the water conditions. Longlines can be fished at any depth, in most weather, and in all current conditions, except perhaps the turbulent boils immediately below the dam spillways and power houses. Most fish would be alive at capture, and therefore of good quality. Incidental mortality of desirable species from hooking and handling is the main potential problem. Also, longlines and associated buoy lines have potential for entanglement conflicts with other boats and fishermen.

Table C-l. Criteria for choice of test gear types:
Most advantageous = 3, least advantageous = 1.

| | Purse seine | Baited longline | Beach seine | Baited pots | set gillnet | Drift gillnet | Trap net |
|---|---|---|---|---|---|---|---|
| Adaptable to present boats | 2 | 3 | 3 | 2 | 3 | 3 | 2 |
| Fishable in most areas | 1 | 3 | 1 | 3 | 3 | 1 | 1 |
| Relatively untested | 3 | 3 | 1.5 | 3 | 1 | 2 | 1 |
| Opinions of others | 2 | 3 | 1 | 1.5 | 1.5 | 1 | 2 |
| High quality of live product | 3 | 2 | 2 | 2 | 1.5 | 2 | 3 |
| Low incidental catch | 3 | 2 | 2 | 2 | 1 | 1 | 1 |
| Ease of handling | 1.5 | 3 | 2 | 2 | 3 | 2 | 1 |
| Suitable in bad weather | 1 | 3 | 1 | 3 | 3 | 2 | 2 |
| Low investment | 2 | 3 | 3 | 2 | 2 | 2 | 1 |
| Tending requirements | 3 | 2 | 3 | 1 | 1 | 3 | 1 |
| Total | 21.5 | 27 | 19.5 | 21.5 | 20 | 19 | 15 |

Beach seining is a simple and inexpensive method easily adapted to small boats. It has advantages similar to purse seining: Live product, ease of release of incidental species, and lack of tending requirements. However, suitable beach seining sites are limited and previous researchers reported very low catch rates of large (>250mm) squawfish using beach seines.

Baited pots have been little tested and could be fished virtually anywhere. They could also be left out in bad weather and would continue to fish. They would probably have to be deployed for considerable time periods (perhaps overnight), which might reduce product quality or even induce mortality of northern squawfish and other species entrapped. Pots are fairly expensive items and untended ones might entice theft.

Gillnetting is perhaps the most commonly used and productive small-boat gear type in the world. Gillnetting is inexpensively adaptable to small boats. Stationary gillnets can be set many places except in heavy current. Drift gillnets can be employed in fast current, but would probably not be efficient out of current. Gillnets are easy to handle and fishable under most weather conditions. Stationary nets may require tending and have potential for entanglement conflict. Since fish captured by gillnets are often dead at capture, product quality of target species may be a problem with gillnets, and there could be adverse impacts on populations of incidentally caught species. Set gillnets have been used extensively for northern squawfish capture in the Columbia River and elsewhere, and abundant data exist on catch rates. Drift gillnets have been less tested.

Trapping is another form of capture that yields a live, potentially high quality target product with good potential for unharmed release of incidentally caught species. Two types of traps have been extensively investigated on the Columbia River, the Merwin trap and the lake trap. The Merwin trap, a modified version of a floating salmon trap, was developed by the Washington Department of Fisheries (Hamilton et al. 1970). A Merwin trap is a large, cumbersome structure with usually a long lead and requiring specialized vessels and considerable manpower to move about and set. Tending and maintenance requirements are high. Merwin traps have been shown to be very effective on northern squawfish in certain situations such as spring (presumably spawning) migration in weather-protected sites. Unless the physical support and float systems were stronger than those previously tested, these traps could not be used effectively along unprotected shorelines or areas of even moderate current.

The lake trap (Nigro et al. 1985) is smaller than the Merwin trap and readily adaptable to small-boat use. Like the Merwin trap, the lake trap cannot be fished in much current and requires considerable cleaning and tending. Furthermore, this gear type was tested for several years in the John Day reservoir during the research efforts involved in assessing northern squawfish and other predator populations. Low catch rates [averaging three squawfish or less per trap haul over extensive tests (Nigro et al. 1985a,b)] and relatively high handling requirements indicated this would probably be an inefficient commercial gear type.

With these considerations in mind, we selected purse-seining and long-lining as potentially effective, relatively untested gear types that should be tested most extensively. We also felt pots should be tested on a spot-check basis. Also, we added gillnets -- both set and drift -- to our repertoire for field testing. We were fairly certain that incidental catch mortality during much of the year would often cause such gear to be inappropriate. However, gillnets have been relatively untested for northern squawfish in the winter, and there were circumstances cited in the literature in which northern squawfish were efficiently captured by such gear (Foerster and Ricker 1941; U.S. Fish and Wildlife Service 1957). Also, gillnetting indices of northern squawfish abundance by age-class were previously established for the John Day reservoir and the cooperating agencies (University of Washington, Oregon Department of Fish and Wildlife, and U.S. Fish and Wildlife Service) desired to maintain continuity in population assessment methodology during the present sampling season. Thus, the use of gillnets was for biological monitoring purposes as (Vigg and Burley 1990) well as for assessing this gear type for commercial fishery potential.

## Description of Purse Seine Gear

Seine length was 350 ft (107 m). Hung depth of the mesh was 25 ft (7.6 m), but the purse rings hung down an additional 2 ft (0.6 m), so the total depth of the gear was 27 ft (8.2 m). Web was #12 knotted twine, 2.5 in. (6.35 cm) stretch mesh in all but the 35 ft (10.7) bunt which was 2 in. (5.08 cm) stretch mesh. Lead-line was 1.50 lbs (68 kg) per 100 fathoms (183 m). Corks were placed every foot (30.5 cm), except in the bunt where they were spaced 6 in. (15.2 cm) apart. Purse line was 7/16-in. (1.1 cm) diameter woven nylon. Initially, the net was hung with 50 purse rings spaced every 7 ft (2.1 m), but this was an excessive number and caused handling difficulty. We therefore removed half, leaving 25 rings at 14 ft (4.3 m) spacing.

Special equipment to fish the seine is shown in Figure C-l. This included a 3 ft (91.4 cm) wide by 3.5 ft (106.7 cm) diameter chain-driven drum; a net level-wind mechanism operated intermittently by a hand control valve; a set of bow fairleads for net retrieval: a boom and block arrangement for pursing and suspending purse rings during retrieval; a 5-m. (12.7 cm) gypsy winch for purse line hauling; a gasoline-driven hydraulic power pack (8 hp gas motor, 6 gpm pump); hydraulic lines (0.5 in., 1.3 cm) and valves; and a "hairpin" for suspending purse rings during retrieval.

This equipment was mounted on the 20 ft (6.1 m) UW Boston Whaler. Two separate vessels were used as seine skiffs during trials: A 14 ft (4.3 m) aluminum skiff with 15 hp outboard, and the 22 ft (6.7 m) ODF&W Whaler with a 200 hp outboard motor. Neither vessel was well suited because they lacked a suitable midship towing bar. The Whaler was more suitable because it could tow from the bow in reverse. This was satisfactory, particularly since it allowed the skiff operator to view the operation without having to turn around.

## Description of Longline Gear

The mainline, gangions, winch, and fairlead are shown in Figure C-2. The longline system consisted of 1.5 mm diameter (250 lb, 113.4 kg test) monofilament groundline with brass-bead stops every meter, nylon gangion snaps with push-on attachment design, and 12 in. (30.5 cm) long monofilament gangions with hooks of various types and sizes. Anchors of 15 lb (6.8 kg) lead-filled steel pipe and A2 Polyform buoys were placed at both ends of a section of groundline. Smaller anchors (5 lb, 2.3 kg sash weights) and floats were attached by halibut snaps to the groundline alternately at various spacing distances to suspend the baited hooks at varying depths off the bottom. A normal set was 50-75 hooks on 300-400 ft (91-122 m) of groundline.

We tested two setting methods: A hand-operated winch, and a hydraulically operated drum. The hand-operated method was the best, since the boat operator could feel the tension on the groundline through the pressure on the winch handle during setting and retrieving, and could adjust boat speed accordingly. Keeping proper tension in the groundline was an important aid to the person snapping or unsnapping the hooks. Hydraulically or electrically operated systems (or an alternate hand reel system) might ultimately be most efficient, but proper location of drum, fairlead, and boat controls is crucial to a smooth operation. In our operation, the reel and fairlead were so arranged

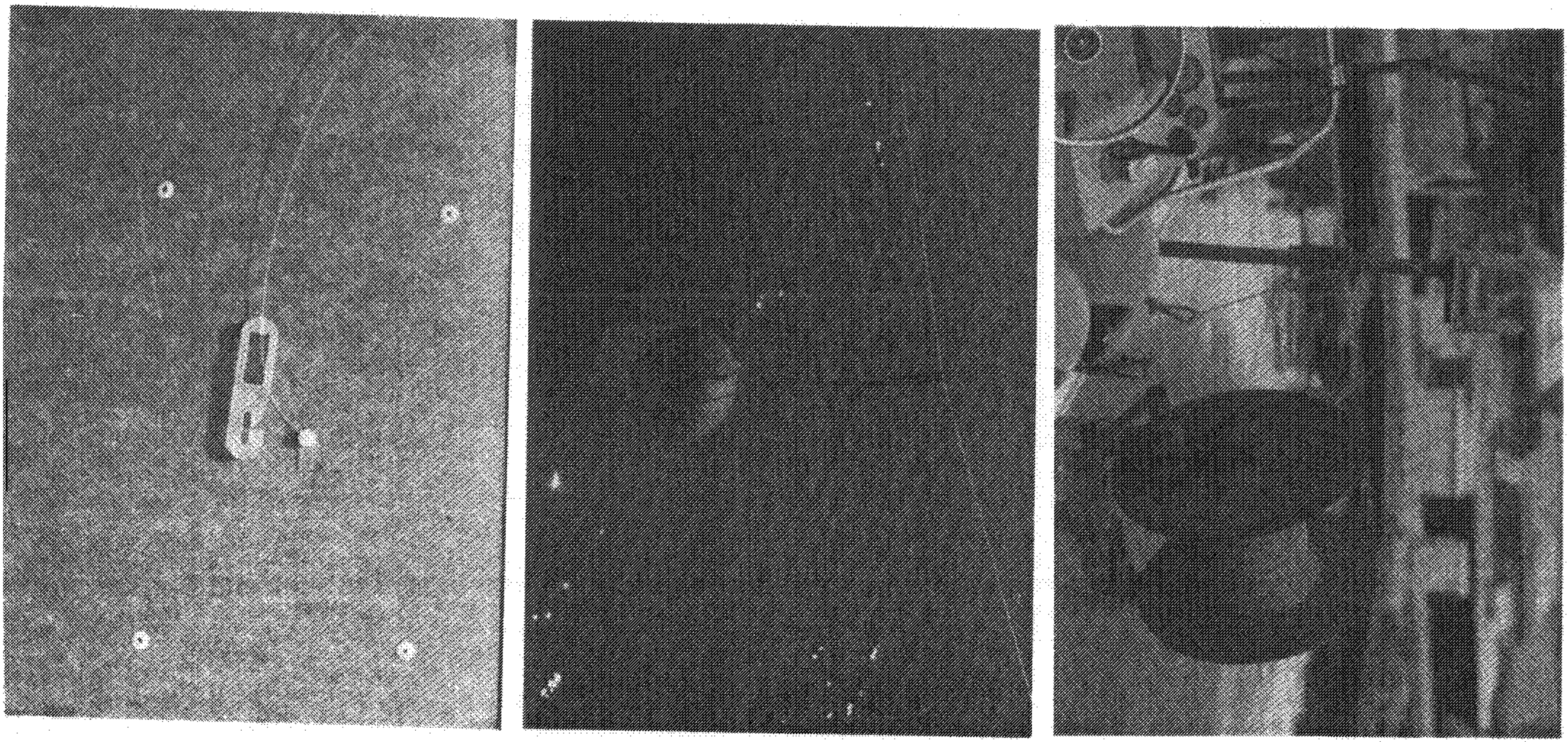


Figure C-2. Longline equipment: Reel, fairlead, snap.

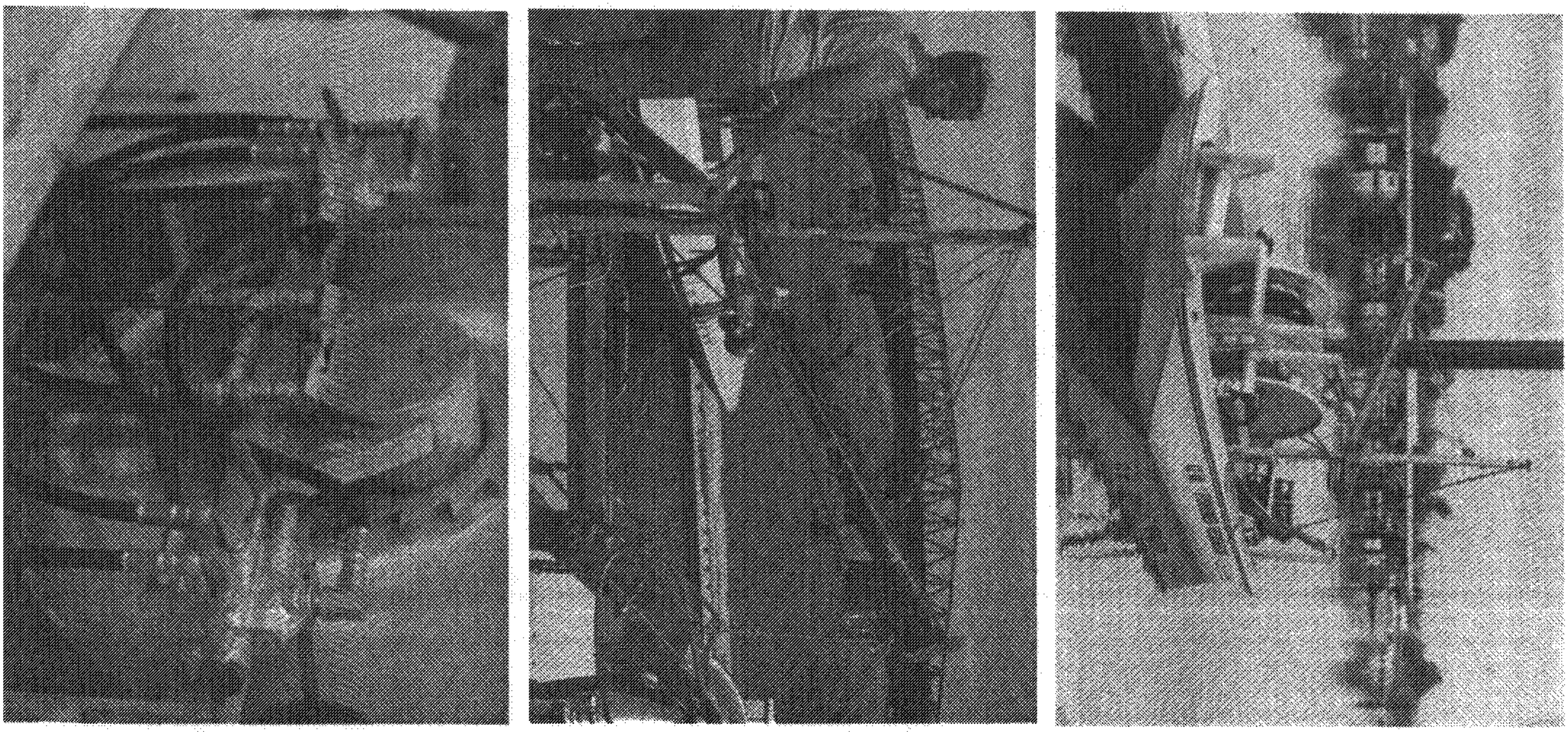


Figure C-1. Purse seine equipment: Drum, fairleads, boom and block, "hairpin," hydraulic valves.

that gear was set in reverse and retrieved in forward over the bow. Two people were needed to operate our gear, but more efficiently designed systems could be operated by one person

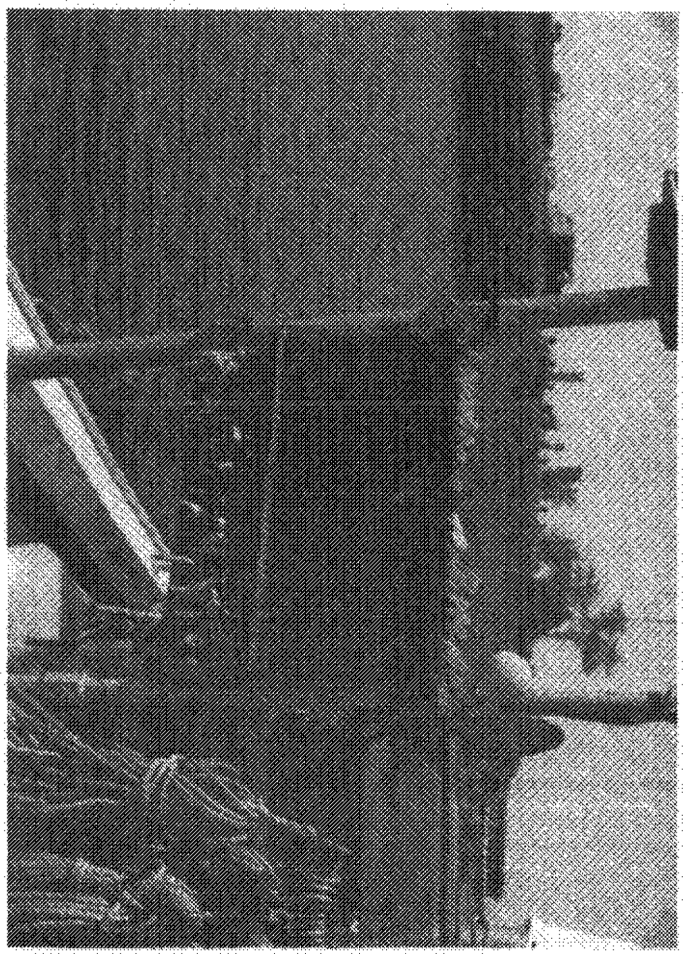
Hooks were normally 3/0 stainless steel "steelhead/salmon" type (Figure C-3). This hook was easiest to bait and unbait and stayed sharp well. Alternative hook styles tested were 2/0 steel Kahle hook (English bait hook), 3/0 tinned circle hook, and 3/0 tinned "J" hook.

Baits were usually whole salmonid smolts (2.5"-4", 6.4-10.2 cm) or cut chunks of salmonid smolts. The smolts were obtained from the McNary Dam smolt collector operated by the U.S. Army Corps of Engineers. Dead smolts are collected regularly on the drift screens. We used fresh, frozen, salted, and salted and frozen baits. We also tested trout-perch, cottids, and cut chunks of squawfish and suckers. Gangions of various breaking strengths were tested, and 30 lb (13.6 kg) test seemed most satisfactory. Materials of lighter test became snarled and twisted. Gangions of 30 lb (13.6 kg) test broke when large sturgeon or catfish were hooked. Large fish which could not break loose tended to foul the gear. The 30 lb (13.6 kg) gangions seldom became snarled or twisted.

The unique gangion snap had a simple but effective swivel mechanism, an important feature which prevented gangions from twisting on themselves or around the groundline. The bitter end of the gangion fastened through a small hole in the snap and was secured by a bead and a double overhand knot (Figure C-2). The gangions were stored on hookboards where they could be baited or debaited as a group before and after being set (Figure C-3).

## Description of Gillnet Gear

Surface nets were 7.5 ft (22.9 m) long and sunken nets were 150 ft (45.7) long. Sunken nets were 10 ft (3.1 m) deep and surface nets were 20 ft (6.1 m). Leadline was 1.1 pound per fathom (0.27 kg per meter), and cork spacing and size were variable as required to float a surface net or allow a bottom net to sink. Mesh sizes of 2.5, 3.5, and 4.0 in. (6.4, 8.9, 10.2 cm) stretch mesh were employed. Each 150 ft (45.7 m) net consisted of six 25 ft (7.6 m) panels, two of each mesh size installed in random order. Anchors (15 lb, 6.8 kg) and buoys were attached to each end of a net. Both bottom and floating nets were set horizontally and generally cross-current. Surface nets were used for both stationary and drift sets. The drift sets were set without anchors as close to the powerhouse as river turbulence allowed and drifted downstream for 15-30 minutes per set.



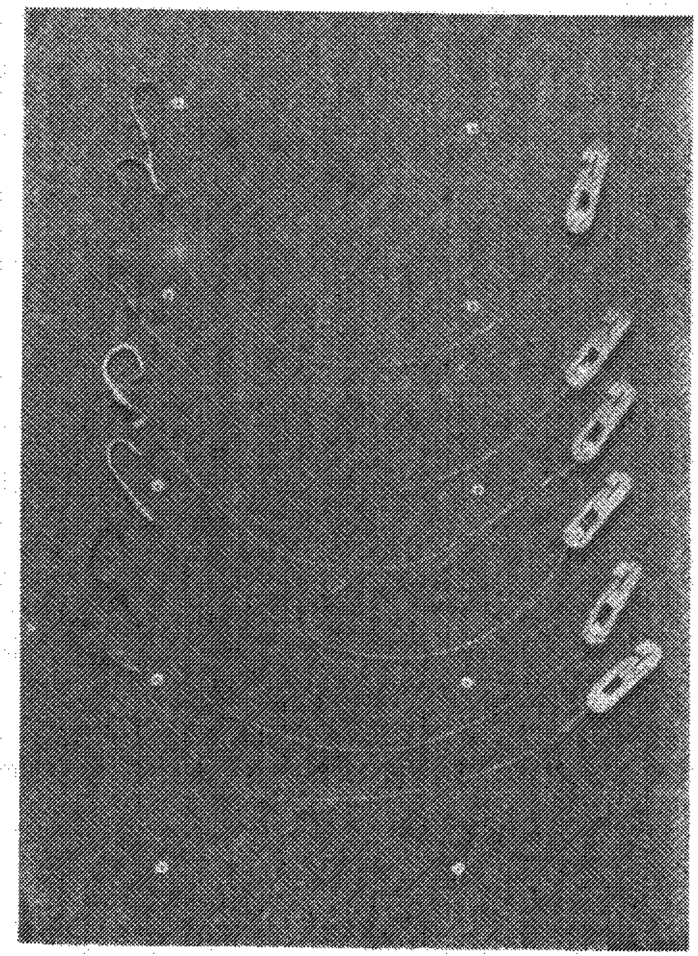


Figure C-3. Longline gear: Hooks, baits, hookboard.

Nets were hand-set and hauled out of 30 gallon (114 liter) plastic garbage cans (Figure C-4). Normally, two people set and retrieved the nets, pulling the boat to the net at retrieval, without power. A hydraulic drum could be used in these operations, in which case one person could handle the nets.

## Description of Pot Gear

Our pots were commercially built shrimp pots (Figure C-S). They consisted of a rectangular iron reinforcing bar framework (18"x18"x36", 46x46x91 cm) covered with 1 inch (2.54 cm) stretch mesh knotless netting. There were in-facing conical tunnels at each end which originally tapered to 1 inch (2.54 cm) diameter openings. The openings were modified to 3, 4 and 5 in. (7.6, 10.2, 12.7 cm) diameter to accommodate entrance of northern squawfish.

Pots were baited with salmon smolts and fished singly with a buoyline on each. Usually, they were fished overnight.

## Purse Seine Field Sampling Procedures

We have not, thus far, seined according to any regular temporal-spatial schedule. Much of the effort consisted of designing, outfitting, physically testing, and modifying the seine in various ways to physically improve its operation.

We first tested the gear in Lake Washington on 5 July, making four complete sets. Because of problems encountered, we modified the net-handling gear in several ways and removed half of the purse rings. On 7 July, we again tested in Lake Washington, making three sets and finding the gear mechanically satisfactory. These sets required approximately thirty minutes to set, retrieve and prepare for the next set.

On 19 July, we tested the gear in mid-channel of the upper John Day reservoir in the vicinity of the Umatilla marina entrance. We surveyed the area with depth sounder first to find a suitably wide section 30 ft (9.1 m) deep or greater. We set, but snagged the bottom. The current (about 2.0 ft per second) caused the whole net to sink, and it was nearly lost. By cutting the purse line we were able to free it.

Figure C-4. Gillnet gear.

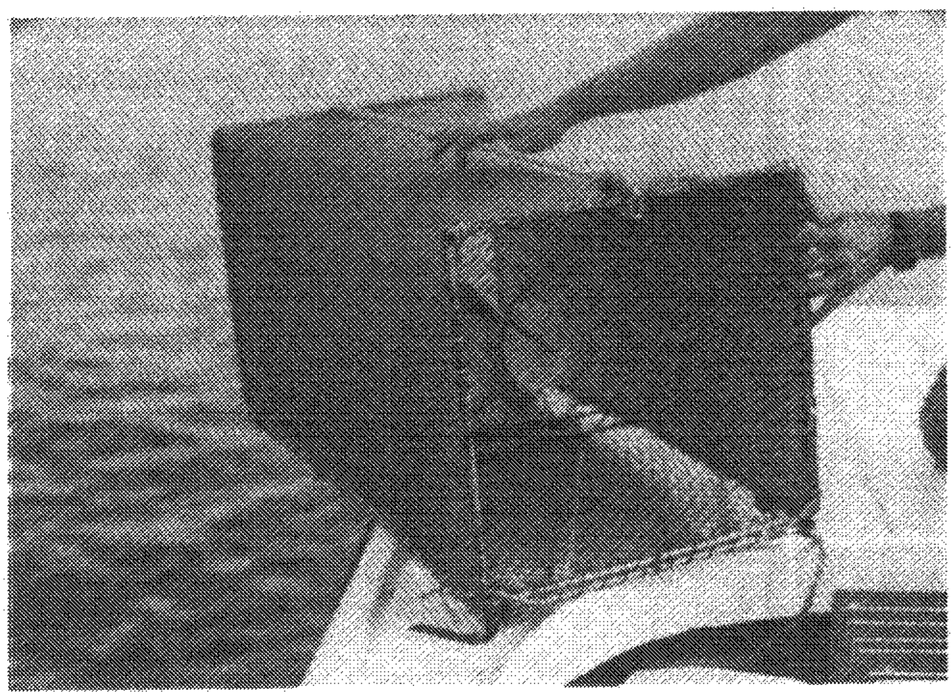


Figure C-5. Pot gear

After repairs to the net, we next seined on 20 and 21 July near the Irrigon hatchery. Water depth was 40-60 ft (12.2-18.3 m) and current approximately 1.0 ft per second. We made five complete sets with no problems encountered. We fished this same area again on 12 August, making four sets at that time. We tried towing the net both upstream and downstream for 15-30 minutes before closing. The seining went smoothly and hauls required about 15 minutes each, or longer, depending on towing time.

We fished the spill basin below McNary Dam on several dates, beginning the week of 17-21 July. The water there was 30-40 ft (9.1-12.2 m) deep. There was little current in the center of the basin at this time. At the south end of the basin, near the Oregon ladder entrance, there was considerable turbulence, however. During one set, we were drawn into the turbulence, which caused the net to collapse and tangle. The net had to be taken ashore to straighten.

We snagged the bottom with the seine several times in the spill basin even though the depth was 30 ft (9.1 m) or greater on the depth recorder. Apparently, the purse line hung down below 30 ft (9.1 m) in places.

We attempted one modification of the seine to allow it to be fished in shallower waters. We raised the leadline by placing vertical 20 ft (6.7 m) lines (#36 seine twine) between the cork and lead lines. These were placed at the breast lines (each end) of the net and above each of the rings. Thus, there were 27 vertical lines in total. So modified, the depth of the seine was limited to 22 ft (6.7 m) (including the 2 ft bridles for the rings). We made four sets with the modified seine in the McNary spill basin on 11 August. Catches of all species were substantially less than catches before modification. Furthermore, tangles were frequent and the seine did not appear to "hang" well. Purse rings tended to get caught between the vertical lines and the web. This modification did not seem to be an appropriate way to shallow the seine, and subsequently, the vertical lines were removed. To effectively shallow this seine, it would be necessary to rehang the net with shallower web.

## Longline and Gillnet Field Sampling Procedures

Five transects were chosen for sampling within the John Day reservoir. These five areas include nearly all habitats identified within the reservoir by past studies (S. Vigg, C.C. Burley, ODF&W pers. comm.). The McNary transect includes the upstream faster current area of the reservoir, the Irrigon, Paterson, and Arlington areas represent slower current areas; and the John Day transect represents the very slow current "pool" portion of the reservoir.

Each transect was sampled during three separate weeks throughout the summer (1.5 May-12 August): Early, mid-, and late summer. A 12-week sampling schedule was devised in order to allow three weeks of sampling at each transect. Irrigon and Paterson transects were fished simultaneously because of their close proximity to one another. Three days of fishing were initially scheduled for each week, allowing two days each week for gear maintenance and laboratory work for the biological samples collected from the bottom gillnets (Vigg and Burley 1990). Generally speaking, this field schedule was met; however, heavy winds sometimes restricted the efficiency of our operations. During one week, the sampling was reduced to two days because of other activities, but the hours per day were increased accordingly.

Surface gillnets, bottom gillnets, and longlines were initially tested, but the surface gillnets were dropped after the first month of sampling season because of their apparent inefficiency and in order to increase sampling effort with bottom gillnets.

The number of sets for each type of gear changed slightly throughout the summer; however, a typical daily routine would be:

- Set three bottom gillnets (or two bottom gillnets and one surface gillnet)
- Set two or three longlines (SO-75 hooks)
- Pull all gillnets
- Set three more gillnets
- Pull all longlines
- Pull all gillnets

With this schedule we were able to fish the bottom and surface gillnets for approximately two hours each and fish the longlines from three to four hours each. Sampling occurred at various hours throughout the day (Table C-2).

Data collected for each piece of gear were basically standard for most sampling: Location, start time and date, stop time and date, gear type, depth gear was fished, water temperature, and numbers of fish caught (Figure C-6). We also tried collecting more general variables, but measurement difficulties were encountered. These variables were water turbidity, substrate type, wave height, and current speed. The Secchi disk reading was difficult to read in high waves (which was a common condition). Wave height was also difficult to measure and very subjective. A 0.025 cubic meter Van Veen grab sampler was

Table C-2. Frequency distribution for time of day of setting gillnets, longlines, and purse seines in the John Day reservoir, April-August 1989.

| | NUMBER OF SETS | | |
|---|---|---|---|
| Hour of day | All Gillnets | Longline | Purse Seine |
| 3 a.m. | 4 | 0 | 0 |
| 4 a.m. | 10 | 2 | 0 |
| 5 a.m. | 8 | 6 | 0 |
| 6 a.m. | 25 | 9 | 0 |
| 7 a.m. | | 4 | 0 |
| 8 a.m. | 22 | 9 | 0 |
| 9 a.m. | 6 | 17 | 0 |
| 10 a.m. | 12 | 7 | 3 |
| 11 a.m. | 18 | 9 | 3 |
| 12 noon | 7 | 8 | 2 |
| 1 p.m. | 5 | 5 | 1 |
| 2 p.m. | 5 | 4 | 5 |
| 3 p.m. | 10 | 1 | 2 |
| p.m. | 7 | 7 | 2 |
| 5 p.m. | 10 | 17 | 0 |
| 6 p.m. | | 1 | 1 |
| p.m. | | | 2 |
| 8 p.m. | 11 | 3 | 0 |
| 9 p.m. | 4 | 3 | 0 |
| 10 p.m. | 0 | 1 | 0 |
| Total | 191 | 114 | 21 |

Personnel ______ Location ______ weather ______ Page ___ of ___

| Location sampled | Gear type | number hooks set | number hooks broken | Start date | | | Start time Military | Stop date | | | Stop time Military | Effort (hours) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | month | day | year | | month | day | year | | |

| Current (ft/s) | Depth min (ft) | Depth max (ft) | Secchi (ft) (inches) | water temp (C) | wave height (ft) | substrate | Number of fish caught (use three letter species code) |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

Bait type:

Bottom temp: °C

| Length Frequency | | <200 | 208-225 | 226-250 | 251-275 | 276-300 | 301-325 | 326-350 | 351-375 | 376-400 | 401-425 | 426-450 | 451-475 | 476-500 | 501-525 | >526 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SQF (Fork Lgth) | 25 | | | | | | | | | | | | | | | |
| | 35 | | | | | | | | | | | | | | | |
| | 40 | | | | | | | | | | | | | | | |

Comments: ______

| Number | Species | Collection number | Total length (mm) | weight (grams) | Mesh size (Gear type) | Hook location | Condition | Sex | Tag Color | Tag number | 2nd mark | Scale taken | Stomach taken | Gonad weight (g) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | |
| 13 | | | | | | | | | | | | | | | |
| 14 | | | | | | | | | | | | | | | |

Figure C-6. Field data form.

initially used to determine bottom substrate; however, it would not retrieve anything but mud and silt. Small rocks would often stick in the jaws and hold the mouth open. It also did not work in heavy current or areas that had twigs and sticks on the bottom. Surface current was measured by the "floating chip" method, but this was suitable only on calm days when the boat speed was zero relative to the water speed.

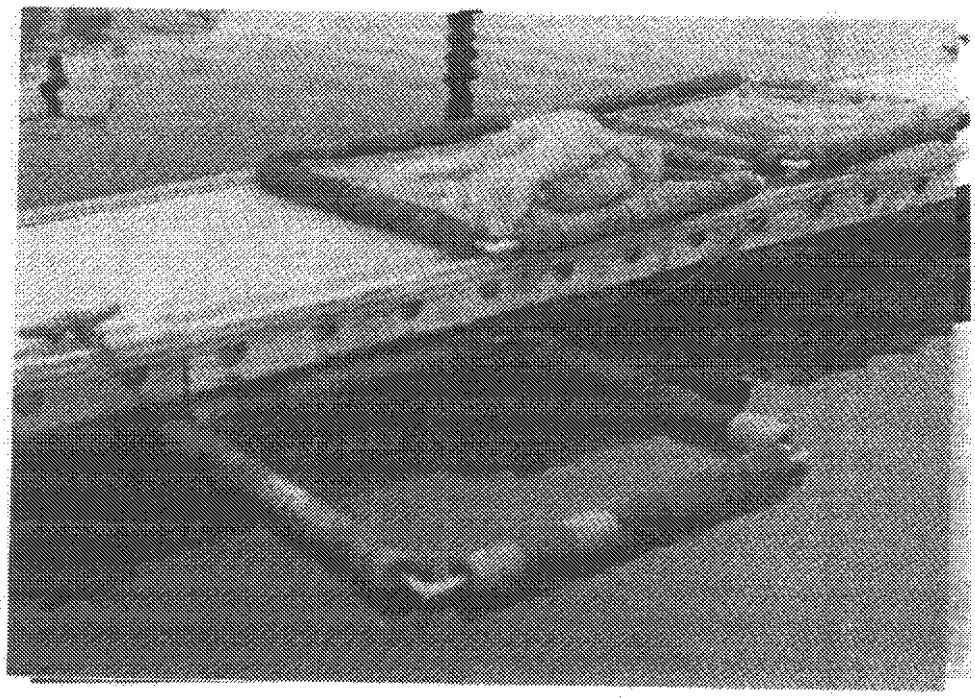
### Live Holding Observations

Recreationally important sportfish caught on the longline were held in live pens to test for hooking mortality. Three 4'x4'x8' deep (1.2x1.2x2.4 m) pens were used as well as one large pen, 8'x20'x8' deep (2.4x6.1x2.4 m) (Figure C-7). The pens were secured to the docks at the Umatilla marina. White sturgeon, *Acipenser transmontanus*, and channel catfish, *Ictalurus punctatus*, caught in the McNary transect were transported by boat in 30 gallon (114 liter) cans to the live pens. Fish were held from three to seven days; however, all observed mortality occurred within the first day.

Due to irregular catches of white sturgeon and channel catfish, holding densities varied greatly. Fish collected throughout a week of sampling were held in a single pen and released at the beginning of the following week.

### Pot Fishing Procedures

We made relatively little effort with this type of gear. One pot was fished continuously for seven days in the Umatilla marina (12 ft, 3.7 m), and three pots were set overnight at the mouth of the Umatilla River on one occasion (7-15 ft, 2.1-4.6 m).



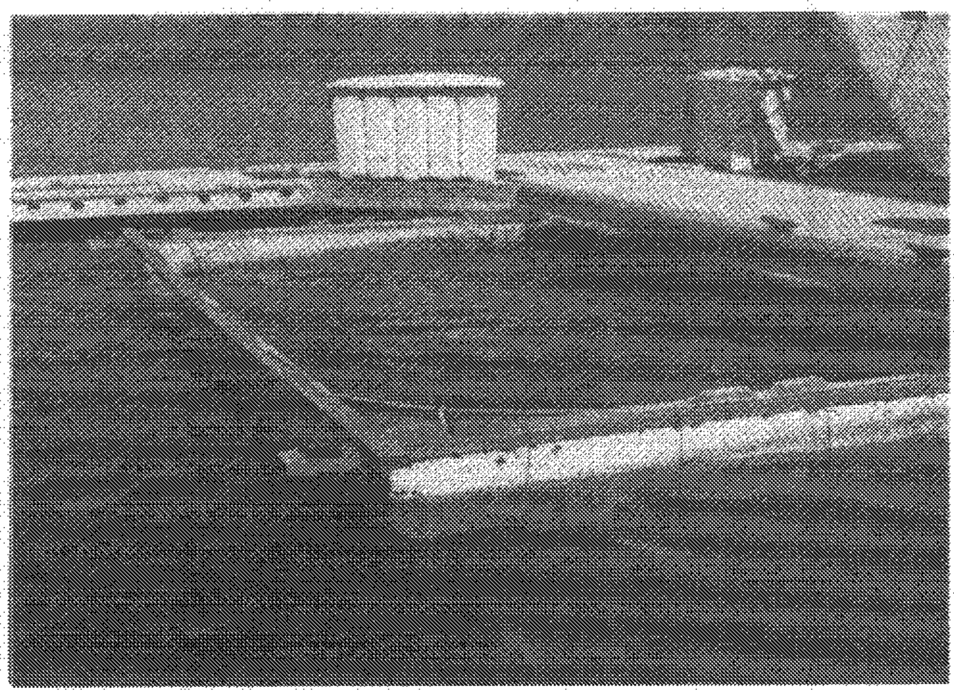


Figure C-7. Live holding pens.

## RESULTS

### Purse Seining

The single set made off the Umatilla Marina (which hung up) did yield 18 American shad, but no other species.

The nine sets made in the vicinity of the Irrigon hatchery yielded no fish. Mechanically, the gear seemed to work well. Because of the net depth and amount of current, we could not get too close to shore, where experience with other gear types suggested that fish would be found. We were restricted to the main channel of the river.

In the McNary spill basin we made a total of 18 successful sets (no hang-ups) between 11 July and 25 August, including four in which the net was “strung” to hang 22 ft (6.7 m) deep. Table C-3 summarizes the catches of all species by purse seine in the McNary spill basin. A total of 88 northern squawfish was caught. American shad was the second most abundant species. With the exception of American shad, all non-squawfish released from the seine appeared healthy. American shad appeared weak at release and on two occasions dead ones were observed in the area after seining. These American shad may have been spawned-out, and thus weakened.

Each set took between 15 and 30 minutes to complete. The catch per unit of effort (CPUE) was calculated at 4.89 northern squaw-fish per set with a mean of about 2.5 minutes per set for the McNary spill basin, which results in a catch per hour of 11.64 northern squawfish.

### Longlining

Longlining was a very successful method in terms of maximum northern squawfish CPUE and minimum incidence of other species in the catch.

In total, we made 115 sets. Number of hooks per set averaged 56 and ranged between 25-150. Average soak time averaged 5.5 hours and ranged from 15 minutes to 20 hours. Total hook-hours was 36,558. The northern squawfish catch totaled 525, which translated to about five fish per set or 0.0244 fish per hook-hour. In terms of hooks set per fish caught, the statistic commonly referred to in commercial longline fisheries, we averaged about 12 hooks/northern squawfish.

Table C-3. Total catch from purse seining at the McNary Dam spillway, July-August 1989. Total number of sets = 18.

| Species | # | % |
|---|---|---|
| Squaw-fish | 88 | 43.56 |
| American shad | 52 | 25.74 |
| Suckers | 31 | 15.35 |
| Carp | 15 | 7.43 |
| Chinook | 5 | 2.48 |
| Steelhead | 4 | 1.98 |
| Sockeye | 3 | 1.49 |
| Chiselmouth | 3 | 1.49 |
| Walleye | 1 | 0.5 |
| Total | 202 | |

Northern squawfish comprised 72% of the fish caught on longlines. Channel catfish and white sturgeon comprised 23%. The remaining 5% was suckers, American shad, carp, cottids, bullheads, and yellow perch. No bass, and surprisingly no walleye were taken on longlines (Table C-4).

In terms of hooks set per northern squawfish caught, the highest success rate was in the McNary section. Here we caught 403 northern squawfish for 3,568 hooks set, an average of one northern squawfish per 8.9 hooks set. Catch rates as high as one fish per 4-5 hooks set were commonly encountered in the McNary section early in our test period. Success tended to decline towards the end of our sampling period. In the Arlington section, an average of 12.7 hooks was set per northern squawfish caught. In the other three sections, longlining was far less successful according to this measure, requiring 23-42 hooks per northern squawfish. The average length of soak time was 5.5 hours.

In terms of the alternative measure of success, squawfish per hook hour, the Irrigon area yielded the highest overall catch rate (Table C-5), followed closely by the McNary section. However, such a comparison may be misleading in that we made a number of overnight sets in the McNary transect but not in the other sections and catch rates per hook hour tended to drop off significantly with length of time set. For all areas combined catch per hook hour was greatest in April, however, sampling effort was quite low during this month. May and July had the next highest catch per hook hour with 0.0228 and 0.0251. McNary and Irrigon transects had the largest catch per hook hour for the total summer sampling period.

Tests to compare baits, hook types, depths of capture, soak time, and other variables affecting northern squawfish catch are ongoing. Specific results will not be given here. However, our sense of these variables thus far suggests that whole, fresh smolts are the best bait; salted smolts are nearly as good; frozen smolts, if salted after thawing, can be effective. Thawed, unsalted smolts are too soft to be effective. Smolts, whole or chunked, are far better baits than cottids or trout-perch of similar size or of chunks of suckers in all transects that bait testing occurred.

The several hook types tested seemed equally efficient. The stainless steelhead/salmon hook has advantages in relative ease of removal from the fish and capability of maintaining a sharp point. The circle hook is very difficult to remove from channel catfish and white sturgeon and for this reason is not recommended and will not be tested further.

Table C-4. Total catch by species from longlining in the John Day reservoir, April-August 1989.

| | PATERSON # | PATERSON % | ARLINGTON # | ARLINGTON % | TRANSECT JOHN DAY # | TRANSECT JOHN DAY % | McNARY # | McNARY % | IRRIGON # | IRRIGON % | TOTAL # | TOTAL % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N.Squawfish | 26 | 60.5 | 57 | 75.0 | 26 | 66.7 | 403 | 75.3 | 13 | 39.4 | 525 | 72.3 |
| C. Catfish | 3 | 7.0 | 11 | 14.5 | 8 | 20.5 | 58 | 10.8 | 3 | 9.1 | 83 | 11.4 |
| W. sturgeon | 4 | 9.3 | 0 | 0.0 | 2 | 5.1 | 60 | 11.2 | 15 | 45.5 | 81 | 11.2 |
| Catostomids | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 4 | 0.7 | 0 | 0.0 | 4 | 0.6 |
| Am. Shad | 0 | 0.0 | 2 | 0.0 | 0 | 0.0 | 2 | 0.4 | 0 | 0.0 | 2 | 0.3 |
| Carp | 0 | 0.0 | 2 | 2.6 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.3 |
| Cottids | 9 | 20.9 | 2 | 2.6 | 1 | 2.6 | 0 | 0.0 | 2 | 6.1 | 14 | 1.9 |
| Bullheads | 0 | 0.0 | 2 | 2.6 | 2 | 5.1 | 3 | 0.6 | 0 | 0.0 | 7 | 1.0 |
| YellowPerch | 1 | 2.3 | 2 | 2.6 | 0 | 0.0 | 5 | 0.9 | 0 | 0.0 | 8 | 1.1 |
| TOTAL | 43 | 0 | 76 | 60 | 39 | | 535 | | 33 | | 726 | |
| #sets | | 11 | | 14 | | 21 | | 59 | | 10 | | 115 |
| #hooks | | 600 | | 722 | | 1100 | | 3568 | | 455 | | 6445 |
| #hook*hours | | 1400 | | 3233 | | 8313 | | 22108 | | 1504 | | 36558 |

Table C-5. Mean catch par hook hour by location, month, and species from longlining in the John Day reservoir for April-August 1989. Catch per hook hour = (# fish caught)/(# hooks fished * # hours fished) calculated for each individual set.

| | | | TRANSECT | | | |
|---|---|---|---|---|---|---|
| MONTH | PATERSON | ARLINGTON | JOHN DAY | McNARY | IRRIGON | ALL AREAS |
| APRIL | | | | | | |
| N.Squawfish | | | | 0.0766 | 0.2667 | 0.1038 |
| | | | | (779) | (8) | (786) |
| MAY | | | | | | |
| N.Squawfish | 0.0133 | | | 0.0247 | 0.0073 | 0.0228 |
| C. Catfish | 0.0133 | | | 0.0048 | 0.0000 | 0.0051 |
| W. Sturgeon | 0.0000 | | | 0.0026 | 0.0073 | 0.0027 |
| Catostomids | 0.0000 | | | 0.0014 | 0.0000 | 0.0012 |
| Bullheads | 0.0000 | | | 0.0009 | 0.0000 | 0.0008 |
| YellowPerch | 0.0000 | | | 0.0005 | 0.0000 | 0.0005 |
| | (150) | | | (5712) | (138) | (6000) |
| JUNE | | | | | | |
| N.Squawfish | 0.0283 | 0.0080 | 0.0016 | 0.0175 | 0.0049 | 0.0122 |
| W. Sturgeon | 0.0052 | 0.0000 | 0.0008 | 0.0009 | 0.0153 | 0.0027 |
| Cottids | 0.0111 | 0.0020 | 0.0001 | 0.0000 | 0.0022 | 0.0021 |
| C. Catfish | 0.0000 | 0.0000 | 0.0004 | 0.0041 | 0.0029 | 0.0019 |
| YellowPerch | 0.0013 | 0.0000 | 0.0000 | 0.0007 | 0.0000 | 0.0005 |
| Bullheads | 0.0000 | 0.0020 | 0.0002 | 0.0000 | 0.0000 | 0.0003 |
| | (637) | (1424) | (5763) | (8630) | (617) | (17071) |
| JULY | | | | | | |
| N.Squawfish | 0.0139 | 0.0331 | 0.0054 | 0.0305 | 0.0098 | 0.0251 |
| W. Sturgeon | 0.0000 | 0.0000 | 0.0000 | 0.0080 | 0.0000 | 0.0042 |
| C. Catfish | 0.0018 | 0.0065 | 0.0034 | 0.0012 | 0.0026 | 0.0026 |
| YellowPerch | 0.0000 | 0.0018 | 0.0000 | 0.0001 | 0.0000 | 0.0004 |
| Bullheads | 0.0000 | 0.0013 | 0.0000 | 0.0000 | 0.0000 | 0.0002 |
| Carp | 0.0000 | 0.0012 | 0.0000 | 0.0000 | 0.0000 | 0.0002 |
| Am. Shad | 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | 0.0001 |
| Cottids | 0.0000 | 0.0005 | 0.0000 | 0.0000 | 0.0000 | 0.0001 |
| Catostomids | 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | 0.0001 |
| | (613) | (1646) | (1750) | (6428) | (742) | (11179) |
| AUGUST | | | | | | |
| N.Squawfish | | 0.0061 | 0.0135 | 0.0341 | | 0.0196 |
| C. Catfish | | 0.0000 | 0.0013 | 0.0062 | | 0.0028 |
| | | (163) | (800) | (560) | | (1523) |
| APRIL-AUGUST | | | | | | |
| N.Squawfish | 0.0217 | 0.0222 | 0.0052 | 0.0308 | 0.0333 | 0.0244 |
| W. Sturgeon | 0.0028 | 0.0000 | 0.0004 | 0.0038 | 0.0069 | 0.0029 |
| C. Catfish | 0.0019 | 0.0037 | 0.0012 | 0.0029 | 0.0022 | 0.0025 |
| Cottids | 0.0061 | 0.0010 | 0.0000 | 0.0000 | 0.0009 | 0.0008 |
| YellowPerch | 0.0007 | 0.0010 | 0.0000 | 0.0003 | 0.0000 | 0.0004 |
| Bullheads | 0.0000 | 0.0014 | 0.0001 | 0.0002 | 0.0000 | 0.0003 |
| Catostomids | 0.0000 | 0.0000 | 0.0000 | 0.0004 | 0.0000 | 0.0002 |
| Carp | 0.0000 | 0.0007 | 0.0000 | 0.0000 | 0.0000 | 0.0001 |
| Am. Shad | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 |
| | (1401) | (3233) | (8313) | (22109) | (1505) | (36561) |
| (total # hook*hours) | | | | | | |

## Gillnetting

Bottom gillnetting was surprisingly ineffectual for northern squawfish and the catch of incidental species was relatively high. Northern squawfish comprised only 14% of the fish caught in the gillnets. Bridgelip and largemouth suckers comprised 59% of the catch in numbers. Important recreational fish (American shad, white sturgeon, channel catfish, walleye, channel catfish, small mouth bass, salmon, steelhead, white crappie, and yellow perch) comprised 25% of the catch in numbers (Table C-6).

Drift gillnetting with 75-ft lengths in the McNary tail race yielded no fish of any kind in two tests.

Surface-floating set nets yielded some fish (Table C-8) but this gear was deemed relatively inefficient after early testing, and therefore was discontinued to allow for increased bottom gillnetting effort and biological data collection. Incidental catch in the surface nets was much lower than bottom gillnets (Table C-8).

A total of 167 bottom gillnet sets was made throughout the reservoir; 165 of these were used for biological monitoring (Vigg and Burley 1990). Soak time averaged 2.37 hours. A total of 122 northern squawfish was caught by bottom gillnets or about 0.3 per gillnet hour overall (Table C-7). Of the 122 northern squawfish, 118 were caught during biological monitoring (Vigg and Burley 1990). The McNary and John Day transects yielded higher northern squawfish catches per gillnet hour (0.45 and 0.39) than the middle three sections. In April only one bottom gillnet was set for one hour in the McNary section and three northern squawfish were caught. Otherwise, the best monthly catch rates were in August.

## Handling Mortality of Incidental Species

There was considerable mortality in the gillnets. Five of nine steelhead were dead after capture. After an overnight set in the McNary section six walleye mortalities were removed from one net. Many channel catfish had to have pectoral and dorsal fin spines removed in order to facilitate release from the gillnet. Also, many suckers were disfigured upon removal from this gear. American shad tended to float after release and most appeared to be moribund. Other mortalities occurred, especially in overnight sets, however, precise records on mortality were not kept.

Table C-6. Total catch by species from bottom gillnetting in the John Day reservoir, April-August 1989.

| | TRANSECT | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PATERSON | | ARLINGTON | | JOHN DAY | | McNARY | | IRRIGON | | TOTAL | |
| | # | % | # | % | # | % | # | % | # | % | # | % |
| Catostomids | 9 | 37.5 | 165 | 79.3 | 215 | 63.4 | 111 | 42.2 | 30 | 50.8 | 530 | 59.4 |
| N.Squawfish | 3 | 12.5 | 23 | 11.1 | 39 | 11.5 | 51 | 19.4 | 6 | 10.2 | 122 | 13.7 |
| Am. Shad | 1 | 4.2 | 7 | 3.4 | 37 | 10.9 | 24 | 9.1 | 7 | 11.9 | 76 | 8.5 |
| w. sturgeon | 2 | 8.3 | 0 | 0.0 | 0 | 0.0 | 44 | 16.7 | 8 | 13.6 | 54 | 6.0 |
| C. Catfish | 1 | 4.2 | 4 | 1.9 | 32 | 9.4 | 7 | 2.7 | 1 | 1.7 | 45 | 5.0 |
| Chiselmouth | 2 | 8.3 | 3 | 1.4 | 7 | 2.1 | 1 | 0.4 | 1 | 1.7 | 14 | 1.6 |
| Walleye | 0 | 0.0 | 1 | 0.5 | 0 | 0.0 | 13 | 0.8 | 0 | 0.0 | 14 | 1.6 |
| Sm.Mth.Bass | 5 | 20.8 | 1 | 0.5 | 3 | 0.9 | 2 | 0.8 | 0 | 0.0 | 11 | 1.2 |
| Steelhead | 1 | 4.2 | 0 | 0.0 | 4 | 0.0 | 2 | [illegible] | 2 | 3.4 | 9 | 1.0 |
| All Carp | 0 | 0.0 | 1 | 0.5 | 2 | 0.6 | 1 | 0.4 | 2 | 3.4 | 4 | 0.4 |
| AllBullhead | 0 | 0.0 | 1 | 0.5 | 2 | 0.6 | 0 | 0.0 | 0 | 0.0 | 3 | 0.3 |
| YellowPerch | 0 | 0.0 | 1 | 0.5 | 0 | 0.0 | 2 | 0.8 | 0 | 0.0 | 3 | 0.3 |
| Chinook S. | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.8 | 0 | 0.0 | 2 | 0.2 |
| Coho Salmon | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.4 | 1 | 1.7 | 2 | 0.2 |
| All Crappie | 0 | 0.0 | 1 | 0.5 | 0 | 0.0 | 0 | 0.0 | 1 | 1.7 | 2 | 0.2 |
| Sockeye S. | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.8 | 0 | 0.0 | 2 | 0.2 |
| TOTAL | 24 | | 208 | | 339 | | 263 | | 59 | | 893 | |
| #sets | | 13 | | 34 | | 48 | | 43 | | 29 | | 167 |
| #gillnet hours | | 25.66 | | 82.48 | | 98.4 | | 131.1 | | 59.08 | | 396.7 |

Table C-7. Mean catch per gillnet hour by species for bottom gillnetting in the John Day reservoir, April-August 1989.

| | | TRANSECT | | | | |
|---|---|---|---|---|---|---|
| MONTH | PATERSON | ARLINGTON | JOHN DAY | McNARY | IRRIGON | ALL AREAS |
| APRIL | | | | | | |
| N.Squawfish | | | | 3.0000 | | 3.0000 |
| MAY | | | | | | |
| Catostomids | 0.2500 | | | 2.2581 | 1.3214 | 1.5219 |
| N.Squawfish | 0.2500 | | | 0.3250 | 0.2857 | 0.2964 |
| Chiselmouth | 0.0000 | | | 0.1250 | 0.2857 | 0.1339 |
| Carp | 0.0000 | | | 0.1366 | 0.0000 | 0.0683 |
| Coho Salmon | 0.0000 | | | 0.1250 | 0.2857 | 0.1339 |
| JUNE | | | | | | |
| Catostomids | 0.2830 | 1.2808 | 1.6346 | 1.0167 | 0.0000 | 0.9845 |
| Am. Shad | 0.0714 | 0.0500 | 0.7137 | 0.2500 | 0.0714 | 0.2812 |
| N.Squawfish | 0.0000 | 0.1578 | 0.2821 | 0.4037 | 0.0000 | 0.2059 |
| C. Catfish | 0.0714 | 0.0500 | 0.2433 | 0.0833 | 0.0000 | 0.1054 |
| W. Sturgeon | 0.1374 | 0.0000 | 0.0000 | 0.2648 | 0.0000 | 0.0845 |
| Chiselmouth | 0.1429 | 0.0628 | 0.0000 | 0.0000 | 0.0000 | 0.0332 |
| Sm.Mth.Bass | 0.0714 | 0.0000 | 0.0805 | 0.0000 | 0.0000 | 0.0316 |
| Walleye | 0.0000 | 0.0000 | 0.0000 | 0.0787 | 0.0000 | 0.0193 |
| YellowPerch | 0.0000 | 0.0500 | 0.0000 | 0.0000 | 0.0000 | 0.0102 |
| Sockeye S. | 0.0000 | 0.0000 | 0.0000 | 0.0417 | 0.0000 | 0.0102 |
| Steelhead | 0.0687 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0098 |
| JULY | | | | | | |
| Catostomids | 0.4722 | 1.8681 | 2.4651 | 1.0475 | 0.6250 | 1.4156 |
| N.Squawfish | 0.2222 | 0.2432 | 0.5143 | 0.3341 | 0.1250 | 0.2878 |
| Am. Shad | 0.0000 | 0.1500 | 0.4778 | 0.2783 | 0.1500 | 0.2387 |
| W. Sturgeon | 0.0000 | 0.0000 | 0.0000 | 0.5895 | 0.2000 | 0.1821 |
| C. Catfish | 0.0000 | 0.0721 | 0.4406 | 0.0887 | 0.0250 | 0.1363 |
| Sm.Mth.Bass | 0.4722 | 0.0240 | 0.0313 | 0.0000 | 0.0000 | 0.0373 |
| Chiselmouth | 0.0000 | 0.0000 | 0.1288 | 0.0000 | 0.0000 | 0.0268 |
| Walleye | 0.0000 | 0.0230 | 0.0000 | 0.0916 | 0.0000 | 0.0262 |
| Carp | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0500 | 0.0130 |
| Steelhead | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0500 | 0.0130 |
| Crappie | 0.0000 | 0.0250 | 0.0000 | 0.0000 | 0.0250 | 0.0130 |
| YellowPerch | 0.0000 | 0.0000 | 0.0000 | 0.0294 | 0.0000 | 0.0065 |
| Bullheads | 0.0000 | 0.0000 | 0.0278 | 0.0000 | 0.0000 | 0.0058 |
| Chinook S. | 0.0000 | 0.0000 | 0.0000 | 0.0096 | 0.0000 | 0.0021 |
| Sockeye S. | 0.0000 | 0.0000 | 0.0000 | 0.0047 | 0.0000 | 0.0010 |
| AUGUST | | | | | | |
| Catostomids | | 3.9808 | 2.3047 | 0.8333 | | 2.1004 |
| N.Squawfish | | 0.2452 | 0.3684 | 0.3827 | | 0.3570 |
| C. Catfish | | 0.0000 | 0.2895 | 0.0000 | | 0.1719 |
| Steelhead | | 0.0000 | 0.1053 | 0.1111 | | 0.0938 |
| W. Sturgeon | | 0.0000 | 0.0000 | 0.2222 | | 0.0625 |
| Am. Shad | | 0.0000 | 0.0263 | 0.1605 | | 0.0608 |
| Chiselmouth | | 0.0000 | 0.0526 | 0.0000 | | 0.0313 |
| Bullheads | | 0.1250 | 0.0263 | 0.0000 | | 0.0313 |
| Sm.Mth.Bass | | 0.0000 | 0.0000 | 0.0988 | | 0.0278 |
| Walleye | | 0.0000 | 0.0000 | 0.0556 | | 0.0156 |
| YellowPerch | | 0.0000 | 0.0000 | 0.0556 | | 0.0156 |
| Carp | | 0.1250 | 0.0000 | 0.0000 | | 0.0156 |

Table C-7 (continued).

| | TRANSECT | | | | | |
|---|---|---|---|---|---|---|
| MONTH | PATERSON | ARLINGTON | JOHN DAY | McNARY | IRRIGON | ALL AREAS |
| APRIL-AUGUST | | | | | | |
| Catostomids | 0.3361 | 1.9439 | 2.1767 | 1.0823 | 0.5222 | 1.4169 |
| N.Squawfish | 0.1068 | 0.2183 | 0.3937 | 0.4481 | 0.1059 | 0.2997 |
| Am. Shad | 0.0385 | 0.1029 | 0.3630 | 0.2134 | 0.1207 | 0.2042 |
| C. Catfish | 0.0385 | 0.0571 | 0.3273 | 0.0583 | 0.0172 | 0.1267 |
| w. sturgeon | 0.0740 | 0.0000 | 0.0000 | 0.3535 | 0.1379 | 0.1207 |
| Chiselmouth | 0.0769 | 0.0185 | 0.0638 | 0.0116 | 0.0197 | 0.0345 |
| Sm.Mth.Bass | 0.1838 | 0.0141 | 0.0322 | 0.0207 | 0.0000 | 0.0318 |
| Steelhead | 0.0370 | 0.0000 | 0.0417 | 0.0233 | 0.0345 | 0.0268 |
| Walleye | 0.0000 | 0.0136 | 0.0000 | 0.0698 | 0.0000 | 0.0207 |
| Carp | 0.0000 | 0.0147 | 0.0000 | 0.0127 | 0.0345 | 0.0123 |
| YellowPerch | 0.0000 | 0.0147 | 0.0000 | 0.0233 | 0.0000 | 0.0090 |
| Bullheads | 0.0000 | 0.0147 | 0.0197 | 0.0000 | 0.0000 | 0.0086 |
| Coho Salmon | 0.0000 | 0.0000 | 0.0000 | 0.0116 | 0.0197 | 0.0064 |
| Crappie | 0.0000 | 0.0147 | 0.0000 | 0.0000 | 0.0172 | 0.0060 |
| Sockeye S. | 0.0000 | 0.0000 | 0.0000 | 0.0135 | 0.0000 | 0.0035 |
| Chinook S. | 0.0000 | 0.0000 | 0.0000 | 0.0038 | 0.0000 | 0.0010 |

Table C-S. Total effort and catch by species for surface gillnets in all transects of John Day reservoir, summer 1989. CPUE = northern squawfish catch per gillnet hour.

| Species | McNary | Irrigon | Paterson | Arlington | John Day |
|---|---|---|---|---|---|
| Catostomids | 2 | 0 | 1 | 6 | 0 |
| N. squawfish | 0 | 0 | 0 | 8 | 1 |
| American shad | 0 | 0 | 0 | 7 | 0 |
| Chiselmouth | 2 | 0 | 0 | 0 | 0 |
| Channel catfish | 0 | 0 | 0 | 1 | 0 |
| Total gillnet-hours | 11.33 | 8.33 | 6 | 26.84 | 6.08 |
| Total gillnets set | S | S | 3 | 7 | 3 |
| Northern squawfish CPUE | 0 | 0 | 0 | 0.30 | 0.16 |

| Totals | |
|---|---|
| Hours | 58.58 |
| Nets | 23 |
| CPUE | 0.15 |

White sturgeon, channel catfish, yellow perch, and American shad were the only game or food species caught by longline. All eight yellow perch caught by longline were dead at capture. This species in every case swallowed the hook completely. Few channel catfish caught by longline were moribund (heavy bleeding) on capture and one of 71 sturgeon was dead on capture. Both species tended to be hooked in the outer mouth parts and could thus be released in relatively unharmed condition.

Live holding experiments with these two species captured on the longline are summarized in Table C-9. Two of 40 sturgeon and 3 of 22 catfish died on holding. All mortalities occurred during the first day of capture and most of these were bleeding from removal of swallowed hooks.

## Baited Pots

In a total of 10 pot nights, one small northern squawfish and three cottids were captured.

Table C-9. Results from liveholding observations with longline captured white sturgeon and channel catfish from June-August 1989.

| Species | Total Held | Mortality | Days Held | % Mortality |
|---|---|---|---|---|
| Sturgeon | 40 | 2 | >3 | 5.0 |
| Catfish | 22 | 3 | >3 | 13.6 |

## DISCUSSION

Based on the results of data collected through August, longlining appears to have greatest potential as a commercial fishing technique. It involves less investment, less handling time, less incidental catch, yet better northern squawfish catches than the other gears tested. Such gear could be easily fished by one- or two-man crews using boats as small as many of the recreational boats used on the reservoirs. Hand-operated gear could also be used. Several potential problems need additional consideration: Impacts on white sturgeon and channel catfish populations, bait availability, and entanglement with sport gear.

Additional live holding with white sturgeon should be done; sample sizes so far are insufficient. Smolts work well as bait but availability for broad use may be impractical or illegal. Alternative baits will be tested further. We encountered sport fishery gear entanglement often enough that this could be a problem with an intensive fishery. Consideration should be given to times and areas of fishing, length of groundline per set, flotation methods, and marking methods in design of regulations. Specific recommendations will be made in our final report.

Gillnetting presents many of the problems initially anticipated. Additionally, we found that bottom-fished gillnets require a good deal of mending. Sticks, rocks, and incidental species produce damage to the web at a rate higher than anticipated. Due to man-hours needed for repair, it may be less expensive to buy new gillnets as older nets degenerate rather than mend old ones. However, either alternative to the problem of gear damage may be relatively expensive.

Purse seining has been disappointing in its yields, particularly since gear and equipment costs were relatively high. Much of the reservoir area where northern squawfish occur is less than 30 ft deep, the minimum depth of our gear. A shallower seine could be built, yet northern squawfish might then tend to swim beneath it. Our initial multi-gear testing at the McNary spillway suggests that northern squawfish may see and avoid the seine. On several occasions, longlines yielded good CPUE on northern squawfish, and these fish were relatively high in the water column, yet subsequent purse seine catches were low over the same area.

Purse seining is normally an effective technique for migrating, schooling pelagic species. Dense schools are commonly observed at the dams (e.g., McNary turbine outlets). Physical conditions may rule out purse seining in a commercial mode; however, control of water output could be coordinated with test fishing activities. The latter such circumstance should be fully considered to take maximal advantage of purse seining as a control technique. Our tests have so far been insufficient to rule out purse seining as a control technique, particularly near dams.

Other control techniques, Merwin traps and Lake traps, should also be considered. They have been proven to be quite efficient as capital intensive, large scale, capture methods. However, it was our feeling that these types of gear did not fall within the three main criteria cited in the introduction to this report, and therefore we spent little effort specifically testing traps. However, in our final report we will analyze trapping results from previous studies and offer a scenario for potential use of such gear in a commercial (or subsidized commercial) fishery for northern squawfish.

# REFERENCES


Foerster, R.E., and W.E. Ricker. 1941. The effect of predaceous fish on survival of young salmon at Cultus Lake. Journal of the Fisheries Research Board of Canada 5:315-336.

Hamilton, J.A.R., L.O. Rothfus, M.W. Erho, and J.D. Remington. 1970. Use of a hydroelectric reservoir for the rearing of coho salmon (*Oncorhynchus kisutch*). Washington Department of Fisheries Research Bulletin 9, 65 pp.

Jeppson, P.W., and W.S. Platts. 1959. Ecology and control of the Columbia River squawfish in northern Idaho lakes. Transactions of the American Fisheries Society 88:197-202.

LeMier, E.H., and S.B. Mathews. 1962. Report on the developmental study of techniques for scrapfish control. Washington Department Fisheries, Contract Report to the U.S. Fish and Wildlife Service, Columbia River Fishery Development Program (14-17-0001-373, 14-17-0001-538), 60 pp.

Nigro, AA., R.C. Beamesderfer, J.C. Elliot, M.P. Faler, L.M. Miller, and B.L. Uremovich. 1985. Abundance and distribution of walleye, northern squawfish, and smallmouth bass in John Day Reservoir, 1985. Oregon Department of Fish and Wildlife, Contract Number DE-A179-82B535097, Annual Report to Bonneville Power Administration, Portland, Oregon. 99 pp.

Nigro, AA., C.F. Willis, R.C. Beamesderfer, J.C. Elliot, and B.L. Uremovich. 1985. Abundance and distribution of walleye, northern squawfish, and smallmouth bass in John Day reservoir and tailrace, 1983. Oregon Department of Fish and Wildlife, Contract Number DE-A179-82BP35097, Annual Report to Bonneville Power Administration, Portland, Oregon 162 pp.

Poe, T.P., and B.E. Reiman, eds. 1988. Predation by resident fish on juvenile salmonids in the John Day Reservoir, 1983-1986. Volumes 1 and 2, Oregon Department of Fish and Wildlife and U.S. Fish and Wildlife Service, Contracts Numbers DE-A179-82BP34796 and DE-A179-82BP35097, Final Report to Bonneville Power Administration, Portland, Oregon.

Poe, T.P., P.T. Lofy, S. Duke, A.A. Nigro, and B.E. Reiman. 1988. Feasibility of various control measures. Pages 153-173 in T.P. Poe and B.E. Reiman, editors, Predation by Resident Fish on Juvenile Salmonids in John Day Reservoir, 1983-1986. Volume 1, Oregon Department of Fish and Wildlife and U.S. Fish and Wildlife Service, Contracts Numbers DE-AI79-82BP34796 and DE-AI79-82BP35097, Final Report to Bonneville Power Administration, Portland, Oregon.

Reiman, B.E., and R.C. Beamesderfer. 1988. Population dynamics of northern squawfish and potential predation on juvenile salmonids in a Columbia River reservoir. Pages 274-307 in T.P. Poe and B.E. Reiman, editors, Predation by Resident Fish on Juvenile Salmonids in John Day Reservoir, 1983-1986, Volume 1, Oregon Department of Fish and Wildife and U.S. Fish and Wildlife Service, Contracts Numbers DE-AI79-82BP34796 and DE-AI79-82BP35097, Final Report to Bonneville Power Administration, Portland, Oregon.

U.S. Fish and Wildlife Service. 1957. Progress report: Squawfish predation study. U.S. Fish and Wildlife Service, Office of Regional Director, Portland, Oregon.

Vigg, S., and C. C. Burley. 1990. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Report A in A. A. Nigro, editor, Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia Basin. Oregon Department of Fish and Wildlife, Contract Number DE-AI79-88BP92122. Annual Report to Bonneville Power Administration, Portland, OR.

**APPENDIX C-l**

# ANNOTATED BIBLIOGRAPHY: PREDATOR CONTROL PROGRAM AND METHODS FOR CAPTURING NORTHERN SQUAWFISH

G. T. Ruggerone, S. B. Mathews, T. Iverson and R. W. Tyler

April, 1989

Bartoo, N.W. 1972. The vertical and horizontal distributions of northern squawfish (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), yellow perch ***(Percaflavescens),*** and adult sockeye salmon ***(Oncorhynchus nerka)*** in Lake Washington. Thesis. University of Washington, Seattle, Washington. 60 p.

Squawfish, peamouth, yellow perch, sockeye salmon, Lake Washington, distribution of fishes in Lake Washington.

During winter, squawfish were concentrated in offshore areas at depths >60 ft, whereas in spring they were most abundant along the shoreline (< 18 ft), excluding bays (< 18 ft). During summer, squawfish were most abundant in bays and along the shoreline. Squawfish tended to inhabit the warmest water available.

This report provides comparative data for squawfish in the Columbia River.

Bentley, W.W., and E.M. Dawley. 1981. Effects of supersaturated dissolved atmospheric gases on northern squawfish, ***Ptychocheilus oregonensis.*** Northwest Science 55: 50-61.

Squawfish, salmon, Snake River, Columbia River, gas supersaturation, predation.

Laboratory studies indicated that mortality of squawfish did not occur at ≤110% of saturation but 32% died in 12 days at 117% of saturation and 100% died in 20 h at 126% of saturation. Average daily food consumption steadily declined from 14.2 g per fish at 100% saturation to 2.3 g per fish at 120% saturation. Field studies indicated that squawfish in the Snake River may not be seriously affected by supersaturation (117-141%) because most squawfish were below 3 m. Predation by squawfish in the river was not affected by supersaturation.

This study shows that squawfish in the tailrace below Little Goose Dam were primarily below 3 m. This may be an important factor during capture of squawfish when adult salmon are migrating up river, e.g., are adult salmon migrating in the upper 3 m?

Brown L.R., and P.B. Moyle. 1981. The impact of squawfish on salmonid populations: a review. North American Journal of Fisheries Management 1: 104-111.

Squawfish, juvenile salmon, western United States, squawfish predation and competition with salmon.

In streams, squawfish do not appear to be significant predators of salmon except in localized, seasonal, or unusual circumstances that are often related to dams or release of smolts from hatcheries. In lakes with large squawfish populations, squawfish can reduce juvenile salmon populations but it is not clear if this predation has any impact on the number of returning adults. Competition between squawfish and trout does not appear to be significant.

This paper provides a useful critique of squawfish predation studies.

Buchanan, D.V., R.M. Hooton, and J.R. Moring. 1981. Northern squawfish (*Ptychocheilus oregonensis*) predation on juvenile salmonids in sections of the Willamette River Basin, Oregon. Canadian Journal of Fisheries and Aquatic Sciences 38: 360-364.

Squawfish, salmon, Willamette River, Oregon, electrofishing, beach seining, squawfish impact on salmon smolts in a free-flowing river.

The authors noted that previous research on the predatory impacts of squawfish on salmon may have been biased by the delay between capture and analysis of stomach contents or by sampling in artificial areas such as below dams. In the Willamette River, only 2% of 1,127 squawfish consumed salmonids, suggesting that squawfish may not be significant predators on salmon smolts in free-flowing rivers.

Clepper, H. 1979. Predator-prey Systems in Fisheries Management. Sport Fishing Institute, Washington, D.C.

Fishes, United States, symposium on predator impacts on economically important prey

The proceedings of this symposium provides an excellent review and some new ideas on predator-prey interactions. Some predator control studies were reviewed but see Meachum &Clark for new information. After reviewing predator-related mortality, Alexander suggested that removal of one predator species would lead to increased predation by other species so that predation might remain constant.

Donnelly, Robert. 1989. Instructor, University of Washington, Seattle, Washington, teaches fishing gear class, personal communication (206-543-2541).

Squawfish, Lake Washington, reproduction.

Donnelly states that squawfish in Lake Washington aggregate in shallow water to spawn (April & May) at two locations: in the mouth of small creeks and in rocky substrate near Seward Park. It is not known whether the spawning ground at Seward Park is influenced by springs.

Elliot, John. 1989. Oregon Department of Fish and Wildlife, Clackamas, Oregon, personal communication (503-657-2035).

Squawfish, Columbia River, comment on capture techniques.

Elliot commented that 2.5-4 inch gillnets are suitable for capturing 200-600 mm squawfish. The largest squawfish in the Columbia River is < 600 mm. Drift gillnets would not be useful because the rocky substrate throughout most of the reservoir would not permit nets to drift. Purse seining to 20-25 ft depths would require care because of shallow water and rocks. He suggests that live baits could be extremely effective. Bait fishes such as minnows and suckers could be seined in several areas.

Faler, M.P., L.M. Miller, and K.I. Welke. 1988. Effects of variation in flow on distributions of northern squawfish in the Columbia River below McNary Dam. North American Journal of Fisheries Management 8: 30-35.

Squawfish, salmon, McNary Dam, Columbia River, water flow effects on squawfish distribution.

Radiotelemetrywas used to examine the effects of water flow below McNary Dam. Squawfish remained in protected shoreline areas during spring and early summer, when discharge rates were high, but moved close to the dam in mid to late summer, when discharge rates were low. During brief flow reductions four of five squawfish moved from the protected areas to the main river channel. Surface water velocities at 81 locations occupied by radio-tagged squawfish ranged from 0 to 70 cm/s (mean, 24.5 cm/s). Water velocities below the tailrace exceeded 100 cm/s.

This paper suggests that the squawfish control program should concentrate in low flow areas.

Fish, J.F., and J.S. Vania. 1971. Killer whale, *Orcinus orca*, sounds repel white whales, *Delphinapterus leucas*. Fishery Bulletin 69: 531-535.

Beluga whale, sockeye salmon, Kvichak River, Alaska, sound, enhance survival of sockeye smolts, commercial salmon fishery.

From 50-500 beluga whales moved up and down the Kvichak River, depending on the tide stage, to feed on sockeye salmon smolts. Sounds of killer whales, which are known to kill and eat beluga whales, were transmitted in the Kvichak River as the whales moved up river. The beluga whales immediately reversed direction and swam downstream. The beluga whales were repelled during several trials. Habituation of the whales to the sound was not thoroughly evaluated.

This study discusses a unique method for reducing predation on salmonids. The use of sound to control squawfish in the Columbia River is not probable (see Meachum 1977).

Fletcher, Doug. 1989. Washington Department of Game, Naches, Washington, warmwater fish biologist, personal communication (509-586-9026).

Walleye, squawfish, Columbia River, hook & line, hooking mortality study on walleye.

Fletcher conducted a hooking mortality study onwalleye in Columbia River reservoirs. Hook & line mortality of sub-legal size walleye was low (1.4%). Walleye congregated in the shallow areas at night to feed; squawfish were often mixed with walleye. Walleye were associated more with the bottom than squawfish. Fletcher suggested that channel catfish might be strongly associated with squawfish in the deeper areas of the reservoir.

Fletcher, D. 1985. Mortality of walleye caught on sport gear and released. Unpublished report. Washington Department of Game, Naches, Washington. 30 p.

Walleye, Spokane River, Lake Roosevelt, hook & line, electrofishing, hooking mortality study on walleye.

A hook and line mortality study was conducted on walleye at the confluence of the Spokane River and Lake Roosevelt during May, 1985. Walleye captured by hook & line (180 fish) and by electofishing (164 fish) were placed in separate but identical net pens. After holding the walleye for 12 days, only one fish died. This fish and another fish whose survival was doubtful were captured by hook & line. Hooking mortality was estimated at 1% based on the mortality of two walleye.

This paper suggests that walleye captured incidentally by the current squawfish control program have a high probability of survival.

Foerster, R.E. and W.E. Ricker. 1941. The effect of reduction of predaceous fish on survival of young sockeye salmon at Cultus Lake. Journal Fisheries Research Board of Canada 5: 315-336.

Squawfish, cutthroat trout, rainbow trout, juvenile sockeye salmon, British Columbia, variable-mesh gillnet, enhancement of commercial sockeye fishery.

During a three-year period the researchers reduced predaceous fish populations (primarily squawfish and char), which feed on sockeye salmon, by about 90%. Mean survival rate of juvenile sockeye (egg to smolt) increased 3.3 times that prior to predator control. Other causes for the increased sockeye survival were discounted. In absolute figures, 3.8 million sockeye smolts, or an expected 380,000 adult sockeye, were saved over the three years. The predator control project was highly cost effective.

This paper is highly relevant to the current Columbia River study. Squawfish were taken in largest numbers from April to early July in gillnets (46 m x 1.8 m) set near shore. This corresponded to their spawning season when squawfish deposit eggs on gravel beaches, often in shallow water. Catch per net-night during spring of the first year of intense fishing averaged 10 fish. Squawfish catches were poor from mid-July to early September using any type of gear. Beginning in mid-September, squawfish move to the deeper parts of the lake and became vulnerable to offshore gillnets set on the bottom. Length frequencies of squawfish (150-450 mm) caught in gillnets of various mesh sizes (51-114 mm or 2-4.5" stretched-measure) suggest that average squawfish length was reduced by the control project, as expected. Beach seines caught numerous squawfish during summer and fall, but they were mostly small (<200 mm, age-l&2). Bait lines and cage traps set during winter captured about 200 squawfish and 400 sculpin. Bait lines caught larger squawfish than the average gillnet size, while those caught in cage traps were considerably smaller. The authors discuss potential side-effects of predator removal, including reduced growth ofjuvenile sockeye and increased age before smoltification.

Hamilton, JAR., L.O. Rothfus, M.W. Erho, and J.D. Remington. 1970. Use of a hydroelectric reservoir for the rearing of coho salmon (*Oncorhynchus kisutch*). Washington Department of Fisheries Research Bulletin No. 9. 65 p.

Squawfish, coho salmon, Lake Merwin, Lewis River, Washington, Merwin trap, gillnet, rotenone, explosives, comprehensive life history evaluation of introduced coho salmon and control of squaw-fish.

Diet and abundance of squawfish indicated that squawfish reduced numbers of juvenile coho released into Lake Merwin. Over 100,000 squawfish were killed from 1958 to 1964 using gillnets, floating traps, rotenone and explosives. Most squawfish were captured in Merwin traps; fishing effort was not provided. Tagging studies did not indicate a significant reduction in squawfish population, indicating significantly more squawfish needed to be killed before coho survival would markedly increased. Squawfish spawned on rocks (S-2.5 cm) at depths between 0.6 and 10.5 m. Most spawning was at 3-6 m.

Hamley, J.M., and H.A. Regier. 1973. Direct estimates of gillnet selectivity to walleye (*Stizostedion vitreum vitreum*). Journal of the Fisheries Research Board of Canada 30: 817-830.

Walleye, Dexter Lake, Ontario, Canada, gill net, gear selectivity.

This paper directly evaluates selectivity of gill nets from the capture of marked walleye. Selectivity of a given mesh size tended to be bimodal, reflecting capture by either wedging or entanglement. As mesh size increased, the amplitude of the selectivity curves increased rapidly. Because the assumption of equal amplitudes is not realistic, the indirect methods (i.e. comparison of unmarked fish captured by two or more mesh sizes) overestimates selectivity curves on the left and underestimates them on the right. Mesh size of 3.5 inch tended to capture 40-60 cm walleye, whereas 4.5 inch gill nets captured 53-68 cm fish.

This paper is useful for examining the selectivity of gill nets in capturing squaw-fish and other fishes in the Columbia River.

Hansen, R. G. 1972. The selectivity of vertical and horizontal monofilament gill nets for peamouth, yellow perch, and northern squawfish in Lake Washington. Thesis. University of Washington, Seattle, Washington. 87 p.

Squawfish, peamouth, yellow perch, Lake Washington, gill net, gear selectivity.

The selectivity of horizontal (set on the lake bottom) and vertical gill nets in capturing squawfish, peamouth and yellow perch was examined in Lake Washington. Horizontal gill nets with stretch-mesh sizes of 2.0, 2.5, 3.0, 3.5, and 4.0 inches were most efficient in capturing squawfish of 254, 334, 344, 384 and 464 mm fork length, respectively. Age-4 squawfish were about 250-275 mm, whereas age-6 fish were about 325-350 mm. A few age-12 squawfish were captured. Female squawfish were larger at a given age than male fish. Horizontal gill nets fished near the bottom were more efficient (# fish/gill net area/h) in capturing fish than vertical nets because squawfish tended to occur near the bottom in water < 60 ft.

The thesis could be useful in determining gill net mesh sizes for capturing squawfish in the Columbia River.

Hubbs, C.L. 1940. Predator control in relation to fish management in Alaska. Transactions of the fifth North American wildlife conference. 5: 153-162.

Char, bald eagle, hair seal, salmon, Alaska, commentary on predator control program to enhance salmon runs.

A predator control program was implemented from 1920-1940 in Alaska, primarily to control char predation on juvenile salmon. A bounty of 2.5-S cents per char tail was paid as an incentive to kill char. The author sites numerous problems with the program, including the unknown effect that char removal would have on the biological community or on the economy of the salmon industry, and killing of valuable rainbow trout and salmon and substituting these as char tails. One bounty hunter reported that he had destroyed over 1.5 million char. The author recommended that Fish and Wildlife employees should remove predators rather than bounty hunters or cannery workers because the program was not properly regulated.

This paper gives some insight into problems that might occur on the Columbia River should a commercial fishery or bounty program be developed for squawfish.

Huntsman, A.G. 1941. Cyclical abundance and birds versus salmon. Journal of the Fisheries Research Board of Canada 5: 227-235.

Kingfisher, merganser, Atlantic salmon, trout, North East Margaree River, bird control to increase Atlantic salmon smolts and adults.

Removal of kingfishers and mergansers from a small tributary of the North East Margaree River corresponded to a 120% increase in the number of Atlantic salmon smolts over the previous year when birds were not removed. Spawning escapement and water height during the smolt migration were excluded as factors influencing the increase in migrating smolts. Bird control on the entire North East Margaree River corresponded to a slight increase in adult returns relative to rivers without bird control. The author concluded that bird control can improve runs of salmon, although increased survival of piscivorous trout may shift the source of mortality. Additional work was needed to determine the long-term effects of predator control.

This project is relevant to the squawfish project because the predators consumed salmon smolts, as do squawfish in the Columbia River. Although additional years of investigation were needed to obtain conclusive results, this study suggests that removal of predators on smolts may increase smolt survival.

Jeppson, P. 1957. The control ofsquawfish by use of dynamite, spot treatment, and reduction of lake levels. The Progressive Fish-Culturist 4: 168-171.

Squawfish, Hayden Lake, Cocolalla Lake, Idaho, Fish Tox, rotenone, gillnets, test methods for killing squawfish, observe spawning.

Methods for controlling squawfish were applied during the time of greatest vulnerability, i.e. during the spawning and developmental period. Squawfish spawned during June and July in water < 12 inches deep. The substrate consisted of 1-8 inch wide rubble. The eggs were adhesive and hatching occurred in 7-8 days in 60-68 °C water. The author suggests that use of dynamite on the spawning ground, slight water level reduction and spot treatment of newly hatched fry with toxicants were effective in controlling squawfish. Estimates of squawfish killed by each method were not provided.

Jeppson, P.W., and W.S. Platts. 1959. Ecology and control of the Columbia squawfish in northern Idaho lakes. Transactions of the American Fisheries Society 88: 197-202.

Squawfish, rainbow trout, kokanee salmon, Hayden Lake, Cocolalla Lake, Pend Oreille Lake, gillnet, dynamite, rotenone, methods to control squawfish for improving sport fishery.

Squawfish were killed using variable-mesh gillnets, dynamite and rotenone. The best mesh sizes for taking spawning squawfish were 3 & 4 inch stretch mesh. The nets were highly selective for females (> 80% of catch) because of their large size relative to males. Catch rates were approximately 0.3-3.5 squawfish per 24 h per 100 ft of 4-inch mesh gillnet. Squawfish were demersal and inhabited depths to 60 ft. Catches were greatest nearshore during the spring spawning period: during fall and winter squawfish were captured offshore. Dynamite was used effectively on the spawning grounds (lake shore and streams) and rotenone was used to kill fry schooling along the shoreline. Squawfish catches declined 90% during 1953-1958 whereas catches of trout doubled. Sportfishing improved during the test period, although this was due in part to increased stocking of trout.

This paper suggests that squawfish are most vulnerable to control measures during the spring spawning period, indicating that identification of squawfish spawning grounds in the Columbia River may be the key to controlling squawfish.

Jonas, Casey. 1989. Commercial bait fisherman and fishing guide, Kalama, Washington, personal communication.

Squawfish observations in the Kalama River.

Jonas reported that squawfish migrate up the Kalama River in June to spawn. Squawfish spawn in dense aggregations up to 10 miles above the river mouth. They could be easily captured by seining or electroshocking. Squawfish readily take natural baits including sand shrimp and salmon eggs.

Lagler, K.F. 1939. The control of fish predators at hatcheries and rearing stations. The Journal of Wildlife Management 3: 169-179.

Herons, merganser, bittern, kingfisher, reptiles, mammals, United States, control of piscivores at hatcheries.

Kinds of fish predators at hatcheries in 38 states are listed. Methods to control predators at hatcheries are discussed. The best predator control methods depends on each hatchery situation.

This paper is not highly relevant to the current project, although it suggests that predators should be controlled at hatcheries as well in the wild. The paper provides ideas for the control of gulls foraging below Columbia River dams.

Laveen, William, D. 1989. Private fisherman, Redding, California, personal communication (phone: 916-223-3509).

Squawfish, salmonids, Sacramento River, California, developing commercial fishery to remove piscivorous squawfish.

Mr. Laveen has a Saltonstall-Kennedy project (7/1/88-6/30/89) to trap squawfish in the fish ladder at Red Bluff Dam on the Sacramento River and sell live squawfish in San Francisco. He offered the following opinions and observations. Squawfish chum easily, i.e., they are attracted easily to scents fromvarious baits such as minnows, sardines, and crawfish. Squawfish are difficult to seine; divers observed large schools swimming under the leadline. Electrofishing was tried but dying squawfish apparently emit pheromones and repel other squawfish. Current market value of squawfish is $1.30/lb and $0.40/lb for live and dressed fish, respectively.

Laveen, William, D. 1989. Squawfish commercial harvest and marketing pilot project. Saltonstall-Kennedy Project Summary. Contact Mr. Laveen (phone: 916-223-3509).

Squawfish, salmonids, Sacramento River, California, developing commercial fishery to remove piscivorous squawfish.

The document describes plans to develop a commercial fishery and market for squawfish in the Sacramento River. A trap for capturing squawfish is being tested. Previous electrofishing attempts were unsuccessful. Mr. Laveen will sell live squawfish to a fish transporter for $0.35/lb. These fish will be sold live in San Francisco markets. The Sacramento River will likely support only one fisherman for squawfish. The project hopes to capture 20,000 lbs of squawfish and therefore improve juvenile salmon survival by about 60%.

LeMier, E.H., and S.B. Mathews. 1962. Report on the developmental study of techniques for scrapfish control. Unpublished report by Washington Department of Fisheries for the Bureau of Commercial Fisheries, United States Fish & Wildlife Service. 60p.

Squawfish, scrapfish, salmonids, Columbia River, feasibility study for enhancement of salmonid populations.

Methods to control scrapfish, primarily squaw-fish, in the Columbia River were evaluated. A number of techniques were considered impractical for scrapfish control on the Columbia River, including poisons, explosives, electrofishing, reservoir drawdown (because of economic factors), and trapping scrapfish in the fish ladders (because of disturbing upstream migrating salmonids). Three gear types with potential commercial application were evaluated during 1961-1962. Long-lining with artificial lures in areas of moderate current was inefficient in capturing squawfish during the brief period of testing; the best catch rate was 9 fish in 5.5 h near the Spring Creek Hatchery. An experimental purse seine (200 ft long x 30 ft deep) was evaluated, primarily for capturing carp, but large concentrations of scrapfish could not be located. The authors concluded that drag (beach) seining, the method commercially employed at the time, was a more practical method for capturing scrapfish. Two floating traps provided the best catches of squawfish. The best catch occurred near the Dalles Dam during four days in late July; 1,928 squawfish were taken. Further analyses indicated that between 15 May and 30August approximately 8,400 squawfish could have been captured by one continuously fishing trap near the Dalles Dam. Two floating traps would have yielded 14,400 fish; six traps 26,800 fish. The authors concluded that because of mechanical problems (torn nets, algae, &wind) and the lack of suitable trap sites, a large scale trapping program on the Columbia River was not practical. Squawfish were believed to spawn in Drano Lake during July based on gonad analyses.

Levy, David. 1989. Salmon biologist. Department of Fisheries and Oceans, West Vancouver, British Columbia, Canada. Personal communication (Home phone: 604-228-9164).

Squawfish, sockeye salmon, Cultus Lake, British Columbia, lake trap, predator control study to increase sockeye production.

Dr. Levy has just received funding to resume the predator control program at Cultus Lake, the site of the Foerster & Ricker predator control study. During 1988, Dr. Levy plans to capture and tag squawfish in order to estimate population size. In subsequent years he will remove squawfish during spring and summer using a lake trap set in the littoral zone. In a recent study, about 5,000 squawfish were captured in 4 months by the lake trap. The lake trap is favored over a gillnet because sportfishes (trout, char & coho) must be released alive. Potential changes in predation rates of char and trout will be examined in the absence of squawfish.

Martin, K., and I. Martin. 1987. Development of an alternative gear for harvesting Columbia River shad, 1986-87. Final Report. Prepared for the National Coastal Resources Research and Development Institute, Newport, Oregon. 22 p.

Shad, summer chinook salmon, lower Columbia River, Newfoundland floating cod trap, selective harvest of shad.

The purpose of the study was to develop a method to selectively harvest shad in the lower Columbia River (below Bonneville Dam) without capturing endangered summer chinook salmon. A Newfoundland floating cod trap (similar to the Lake Met-win trap) was tested for catch efficiency during the first year of study. Numerous problems were encountered, including maintenance of the net in the current, debris, algae, few shad in the lower river, boat size and unexpected rigging costs. The investigators thought most of these problems could be overcome. The net captured shad, juvenile sturgeon, steelhead, salmon and suckers. Marketing of shad appeared to be better than anticipated.

Martin, K., and I. Martin. 1988. Development of an alternative gear for harvesting Columbia River shad, 1987-88. Final Report. Prepared for the National Coastal Resources Research and Development Institute, Newport, Oregon. 9 p.

Shad, summer chinook salmon, lower Columbia River near Welch Island, Newfoundland floating cod trap, selective harvest of shad.

The purpose of the study was to develop a method to selectively harvest shad in the Columbia River without capturing endangered summer chinook salmon. During the second year of study, the floating cod trap was modified slightly. Problems with the river current and bycatch continued in 1987-88 and the investigators recommended that the project be terminated. Although catch records were not provided, the investigators indicated that squawfish were abundant in the lower Columbia River.

Maxfield, G.H., G.E. Monan, and H.L. Garrett. 1969. Electrical installation for control of the northern squawfish. United States Fish and Wildlife Service Special Scientific Report No. 583. 14 p.

Squawfish, Cascade Reservoir, Idaho, electricity, trap, experiment to trap squawfish for purpose of control.

Electricity was tested in Cascade Reservoir, Idaho, as a means to attract squawfish into traps during their spawning migration. Significantly more squawfish entered the traps when power (140-180 volts, A.C.) was on (354 fish) than off (110 fish). A variety ofvoltages, pulse durations and frequencies were tested. Other fish species were also captured in the traps.

This study demonstrated that electricity could be used to enhance catches of squawfish. However, electricity may not be useful for controlling squawfish in the Columbia River because of safety and because of the need for electrical generators when fishing away from the dams.

Maxfield, G.H., R.H. Lander, and C.D. Voltz. 1970. Laboratory tests of an electrical barrier for controlling predation by northern squawfish. United States Fish and Wildlife Service Special Scientific Report No. 611. 8 p.

Squawfish, salmon, Drano Lake, Columbia River, electricity, control movements and predation of squawfish below hatcheries.

Preliminary laboratory results suggest that squaw-fish will avoid electrical fields, which could be used to reduce predation during releases of hatchery smolts. Although results may vary with water temperature and resistivity, these data suggest that electrodes spaced 61 cm apart were most effective. Approximately 85%, 93%, and 96% of the swimming squawfish were blocked by voltage gradients of 0.75, 1.00, and 1.25 volts/cm, respectively.

Electricity appears to have potential for blocking movements of squawfish, although field testing is needed.

Meachum, C.P. 1977. Arctic char predation assessment and control investigations within the Wood River system, Alaska, 1975 and 1976. Bristol Bay Data Report No. 75., Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage, Alaska. 79 p.

Arctic char, sockeye salmon, Wood River, Alaska, purse seine, control predation by char on sockeye salmon.

Arctic char were captured by purse seine, gillnet, beach seine, and hook & line in several rivers within the Wood River system. The purse seine (53 m long, 9 m deep, 4.4 cm stretch mesh) set from an 18 foot skiff was the most effective gear. Up to 400 char could be captured per set. An estimated 3.86 million sockeye smolts or 15.5% of the total sockeye run were consumed by char in three rivers during 1976. In 1975, approximately 1.7 million smolts or 19.5% of the total estimated population were consumed by char in one river. Char captured by the various gear types were held in net pens; no obvious health problems occurred. Killer whale sounds were played underwater as a means to decrease predation by char in rivers but were unsuccessful. The estimated value of sockeye salmon save by the char removal program in 1976 was $778.000.

Meachum, C.P., and J.M. Clark. 1979. Management to increase anadromous salmon production. Pages 377-386 in H. Clepper, editor. Predator-prey Systems in Fisheries Management. Sport Fishing Institute, Washington, D.C.

Arctic char, sockeye salmon, Wood River lakes, Bristol Bay, Alaska, small purse-seine, enhancement of commercial sockeye fishery.

Arctic char are a major predator of migrating sockeye salmon smolts in the Wood River lakes. Most predation occurs at rivers connecting the series of five large lakes where mortality may exceed 50%. During 1977, 5,592 char were captured at the Agulowak River with a small purse seine (up to 400 fish/set), tagged and placed in net pens. Based on concurrent estimates of char feeding rates in the river and the number of char removed, the authors estimated that approximately 907,000 smolts were saved. The benefit-cost ratio was estimated at 6:1. The apparent success of this project was due to the large aggregations of char at the mouth of the rivers and the relative ease of capture. Statistical analysis of sport-fishing catch-per-effort data indicated that fishing for char remained good regardless of the removal program.

This paper suggests that predator control programs should locate areas of predator aggregation. The authors assumed that smolts consumed by char would have experienced similar marine survival as those not consumed. This may not be accurate because char appear to select parasitized smolts more readily than healthy smolts.

Miller, Dave. 1989. National Marine Fisheries Service, Astoria, Oregon, personal communication (phone 503-861-1818).

Squawfish, Columbia River, comments on purse seining for squawfish.

He built a fully-corked purse seine (35 ft x 700 ft , 0.44 inch stretch mesh) to capture squawfish in the Columbia River. The net was effective near the McNary spillway, catching several dozen to over 100 squawfish per set. Catch per effort was similar during the night and day. Fishing at the mouth of John Day River in water nearly 100 ft deep yielded good catches on several occasions. The 35 ft deep purse seine (hung even) fished to about 20 ft. There were no snag problems in the McNary tailrace. He recommended 1.5-2.0 inch web for the main part of the seine. Angling in the main part of the reservoir was similar to seining in effectiveness; squawfish were churned off the bottom with smolts, then caught on lures.

Nigro, A. & others. 1985 a. Abundance and distribution of walleye, northern squawfish and smallmouth bass in John Day Reservoir. Annual progress report, 1983. Oregon Department of Fish and Wildlife. 99 pp.

Squawfish, walleye, smallmouth bass, Columbia River, drift and stationary gill nets, trap nets, boat electrofishing, hook and line, radio tag tracking, angler survey, abundance and distribution of salmon predator populations.

A variety of gear types were used to capture and tag squawfish during 28 March to 23 September, 1983. Abundances of squawfish (> 250 mm) were approximately 32,000 below John Day Dam, 11,000 in John Day forebay, and 28,000 in upper John Day pool. Squawfish were 100% more abundant in the boat restricted zone after spilling stopped. Abundance of walleye (> 250 mm) was 7,000 below John Day Dam and 9,500 in the upper John Day pool.

The highest catch per hour for squawfish occurred during electrofishing (6.9 fish/h, primarily below McNary tailrace), angling (2.3 fish/h, primarily below McNary tailrace), and bottom and surface gillnets (1.6-2.3 fish/h). Squawfish captured by electrofishing were smaller than those captured by other methods. Many of the squawfish radio tagged below the dams tended to stay in that region.

Nigro, A. & others. 1985 b. Abundance and distribution of walleye, northern squawfish and smallmouth bass in John Day Reservoir. Annual progress report, 1985. Oregon Department of Fish and Wildlife. 162 pp.

Squawfish, walleye, smallmouth bass, Columbia River, gill nets, trap nets, boat electrofishing, hook and line, radio tag tracking, angler survey, characteristics of salmon predator populations.

A variety of gear types were used to determine the distribution, abundance, and rate of growth and mortality of squawfish, walleye, and smallmouth bass in John Day Reservoir. Squawfish (primarily 250-450 mm) were distributed throughout the reservoir, whereas 88% of the walleye were captured in McNary tailrace or Irrigon-Paterson and 95% of smallmouth bass were caught from Irrigon-Paterson to the John Day forebay. Radio tag data indicated that squawfish and walleye moved throughout the reservoir, although they tended to be close to shore during period of high water velocity. Squawfish were captured in greatest quantities during May-July. Abundances of squawfish (>250 mm), walleye (>250 mm) and smallmouth bass were approximately 16,000, 95,000, and 11,000 fish, respectively.

Detailed records of catch data are given in an appendix and may be used for comparison in the squaw-fish control study. Greatest catches of squawfish were made by electrofishing (3-4 fish/h) and the small mesh bottom gillnet (1.34 fish/h).

Olney, F.E. 1975. Life history and ecology of the northern squawfish, *Ptychocheilus oregonensis*, in Lake Washington. Thesis. University of Washington, Seattle, Washington. 75 p.

Squawfish, Lake Washington, horizontal and vertical gillnets, ecology of squawfish.

Squawfish were concentrated in the deep lake region in winter, then moved inshore in the spring and winter, based on horizontal gillnet catches (1-5 inch stretch mesh). Vertical gillnets also indicated that squawfish were near the bottom during winter, then moved into the warmer surface waters during summer. Cottids were the dominant prey of large squawfish (> 300 mm); sockeye salmon represented 8.9%-25.6% of the diet byweight. Male squawfish reached sexual maturity at age-4 (251-275 mm) and females matured between age-4 and age-6 (301-350 mm). Squawfish spawned between early June and early August. Fecundity of squawfish 342-590 mm (total length) ranged from 6,037 to 95,089 eggs.

Patten, B.G., and D.T. Rodman. 1969. Reproductive behavior of northern squawfish, *Ptychocheilus oregonensis*. Transactions of the American Fisheries Society 98: 108-111.

Squawfish, Merwin Reservoir, Columbia River, scuba, observed spawning of squawfish for predator control projects.

Spawning squawfish were observed along the talus slope area of Merwin Lake. Most fish were well above the thermocline at 15 m and occupied an area with a 30° slope. Most spawning was on the rocky substrate below 3 m. The distinct spawning coloration and the darting spawning behavior of squawfish is described. Squawfish eggs were demersal, adhesive, pale orange, and about 1 mm in diameter. Fish, including other squawfish, consumed some of the unprotected eggs.

This information may be useful in locating squawfish spawning grounds in the Columbia River.

Poe, T.P., and B.E. Rieman (eds). 1988. Predation by resident fish on juvenile salmonids in John Day Reservoir. Volumes 1 & 2. Final Report. Bonneville Power Administration, Division of Fish and Wildlife, Portland, Oregon.

Squawfish, walleye, smallmouth bass, channel catfish, salmon, steelhead, John Day Reservoir, gill nets, trap nets, boat electrofishing, hook and line, radio tag tracking, angler survey, modelling, etc., predator control to enhance salmon survival.

The purpose of this comprehensive study was to describe predation-related mortality of juvenile salmon relative to other mortality sources and to suggest predation control measures. Approximately 1.9-3.3 million juvenile salmon or 9-19% of the population were consumed annually by fish predators in John Day Reservoir. These estimates are similar in magnitude to those losses estimated for salmon in individual reservoirs and similar or higher than those estimated for passage at each dam. Northern squawfish represented approximately 78% of the predation-related mortality. Consumption rates of squawfish were greatest in May and July when smolts were most abundant but percent-mortality was greatest in August. Most predation occurred in the body of the reservoir, although the McNary Dam tailrace boat restricted zone had the highest level of predation per unit area (22%). Predation may vary at least three-fold depending on the abundance and size structure of the predator populations. Sustained exploitation at 10-20% annually could result in a substantial reduction in the squawfish population (>50%). Potential negative effects of squawfish removal on salmon survival are discussed and numerous recommendations are made.

The papers within this report provide valuable background information for the present squawfish removal study.

Raymond, H.L., W.W. Bentley, and C.S. Thompson. 1974. Effects of power peaking operations on juvenile salmon and trout migrations, 1973. Progress report prepared by National Marine Fisheries Service, Northwest Fisheries Center, Seattle, WA 31 p.

Squawfish, juvenile chinook salmon, Columbia River, Snake River, effects of dams on salmonid smolts, predator abundance.

Timing, travel time, survival and residualism of salmonid smolts in the Snake and Columbia Rivers were evaluated. Additionally, squawfish were captured in a Merwin trap at the Lower Monumental Pool, tagged and released as part of a four year study on the effects of power peaking operations on squawfish abundance. Large numbers (1,000's) of squawfish were captured in December by the trap. During October, 30-40 squawfish were captured per purse seine set in mid-channel; only incidental catches were made in John Day and McNary reservoirs but these fish were considerably larger. Very few squawfish were captured in the tailraces of dams during fall.

Raymond, H.L., C.W. Sims, R.C. Johnsen and W.W. Bentley. 1975. Effects of power peaking operations on juvenile salmon and trout migrations, 1974. Progress report prepared by National Marine Fisheries Service, Northwest Fisheries Center, Seattle, WA. 46 p.

Squawfish, juvenile chinook salmon, Columbia River, Snake River, effects of dams on salmonid smolts, predator abundance, nitrogen supersaturation.

Timing, travel time, survival and residualism of salmonid smolts in the Snake and Columbia Rivers were evaluated. Additionally, 87,501 squawfish were captured in a Merwin trap located in the Palouse River arm of Lower Monumental Pool. Most squawfish were captured in April, May and June. Approximately 18,000 of these fish were adults (150-465 mm). Tag recoveries indicated that only a small proportion of the population was captured. Purse seines collected 2,111 squawfish in the tailrace of Little Goose Dam between 29 April and 8 August (6.5 squawfish per set in April and May vs. 155 squawfish per set in July and August). During April-July a Merwin trap set in shallow water in John Day and The Dalles reservoirs captured squawfish more effectively than a purse seine set in mid-channel but this trend was reverse in August-September. Few squawfish were capture in the John Day tailrace during August-November. Diel studies suggested that squawfish may be more susceptible to purse seining at night. Field and laboratory studies indicated that squawfish were vulnerable to nitrogen levels above 117% saturation and that nitrogen saturation may reduce their feeding rate.

Rensel, J. and K.L. Fresh. 1984. Evaluation of potential species interaction effects in the planning and selection of salmonid enhancement projects. Unpublished report prepared by Washington Department of Fisheries for the 1980 Salmon and Steelhead Conservation Act. 80 p. Contact Kurt Fresh, Washington Department of Fisheries, Olympia, Washington.

Fishes, predation, competition, species interactions and salmon enhancement.

This report provides an excellent review of predator-prey interactions and competitor interactions among salmon populations. The discussion integrates fish interactions with salmon enhancement projects.

Rieman, BE. and R.C. Beamesderfer. 1988. Population dynamics of northern squaw-fish and potential predation on juvenile salmonids in a Columbia River Reservoir. Pages 274-307 in T.P. Poe (editor). Predation by resident fish on juvenile salmonids in John Day Reservoir, 1983-1986. Final Report. United States Department of Energy. Bonneville Power Administration, Portland, Oregon.

Squawfish, salmon, John Day Reservoir, modelling, squawfish predation on salmonids.

The authors suggest that sustained exploitation of squawfish in John Day Reservoir (10%-20% annually) would reduce predation on salmon smolts by >50%, based on simulation modelling. Limited but sustained exploitation of squawfish is suggested as an alternative to more radical control measures. Predator control programs should evaluate compensation by predators.

Ruggerone, G.T. 1989. Predator-prey interactions between piscivorous coho salmon and juvenile sockeye salmon in the Chignik Lakes, Alaska: implications for salmon Management. Ph.D. Dissertation, University of Washington, Seattle, Washington. In preparation.

Coho, sockeye, Dolly Varden char, Chignik Lakes, Alaska, beach seine, gillnet, predation related mortality of sockeye salmon caused by coho salmon.

Consumption of recently emerged sockeye fry by juvenile coho salmon in Chignik Lake, Alaska, was estimated from two independent estimates of daily consumption by individual coho (gastric evacuation and bioenergetic methods) and two independent estimates of coho abundance (reconstruction from adult run size and juvenile catch per effort). Average daily predation rates during 1985-1987 ranged from 1.9 fry coho$^{-1}$ day-l to 3.6 fry coho$^{-1}$ day-l, depending on fry abundance. Estimates of sockeye mortality due coho predation during 1985-1987 were 72, 27, and 84 million sockeye fry, or 52%, 18%, and 84% of the total fry population, respectively. Because the spawning density of coho salmon has more than doubled in recent years, a fixed spawning escapement of coho salmon was recommended to reduce and stabilize predation on juvenile sockeye salmon. Eradication of coho salmon was not recommended because of density-dependent growth of juvenile sockeye and other potential indirect effects.

Ruggerone, G.T. 1986. Consumption of migrating juvenile salmonids by gulls foraging below a Columbia River dam. Transactions of the American Fisheries Society 115: 736-742.

Ring-billed gulls, salmon and steelhead smolts, Wanapum Dam, Columbia River, estimates of smolt mortality caused by gulls.

Ring-billed gulls foraging below the turbine area of Wanapum Dam consumed approximately 50 - 562 salmonid smolts per hour depending on smolt abundance. The number of smolts consumed by gulls during 25 days of peak salmonid migration was approximately 112,000 - 119,000 fish. This estimate was considered a minimum value because additional predation occurred below the spill area. Inexpensive, nonlethal measures to control gulls foraging below Columbia River dams were recommended to enhance salmonid survival.

Sims, C.W., R.C. Johnsen and W.W. Bentley. 1976. Effects of power peaking operations on juvenile salmon and trout migrations, 1975. Progress report prepared by National Marine Fisheries Service, Northwest Fisheries Center, Seattle, WA. 56 p.

Squawfish, juvenile chinook salmon, Columbia River, Snake River, effects of dams on salmonid smolts, predator abundance, nitrogen supersaturation.

Timing, travel time, survival and residualism of salmonid smolts in the Snake and Columbia Rivers were evaluated. Additional work involved squawfish. Purse seine and Merwin trap operations and counting at the fish ladders led the authors to believe that squawfish may be migrating through Columbia River dams and spawning in the tailrace areas below Snake River dams. A drift gillnet (22 ft deep) set below Little Goose dam in May indicated that nearly all squawfish were below 10 ft. Squawfish below 10 ft would not be susceptible to gas bubble disease.

Sims, C.W., R.C. Johnsen and W.W. Bentley. 1977. Effects of power peaking operations on juvenile salmon and trout migrations, 1976. Progress report prepared by National Marine Fisheries Service, Northwest Fisheries Center, Seattle, WA. 27 p.

Squawfish, juvenile chinook salmon, Columbia River, Snake River, effects of dams on salmonid smolts, predator abundance.

Timing, travel time, survival and residualism of salmonid smolts in the Snake and Columbia Rivers were evaluated. Studies of squawfish distribution, abundance and movement continued in 1976. Approximately 100,000 squawfish migrated through the fish ladders of seven dams. The Merwin trap and purse seine were the primary method for capturing squawfish. Tag and recapture studies indicated a population of about 133,000 squawfish in the upper half of Lower Monumental reservoir. Approximately 21% of the squawfish below Lower Granite Dam contained salmonids.

Sims, C.W., R.C. Johnsen and W.W. Bentley. 1978. Effects of power peaking operations on juvenile salmon and trout migrations, 1977. Progress report prepared by National Marine Fisheries Service, Northwest Fisheries Center, Seattle, WA. 52 p.

Squawfish, juvenile chinook salmon, Columbia River, Snake River, effects of dams on salmonid smolts, predator abundance, nitrogen supersaturation.

Timing, travel time, survival, diel movements and residualism of salmonid smolts in the Snake and Columbia Rivers were examined. Squawfish populations below Little Goose and Lower Granite Dams during spring were estimated at 75,000 and 45,000 fish, respectively. Approximately 90% of the squawfish contained salmonids.

Shetter, D.S., and G.R. Alexander. 1970. Results of predator reduction on brook trout and brown trout in 4.2 miles (6.76 km) of the North Branch of the Au Sable River. Transactions of the American Fisheries Society 99: 312-319.

Large brown trout, merganser, Michigan, electrofishing, bird harassment, enhance sport fishery for trout.

During 1964-66 an estimated 40-60% of the brown trout population > 305 mm were removed from the reservoir by electrofishing for the purpose of increasing the survival of smaller brook and brown trout. Occasional harassment of mergansers did not appear to reduce merganser abundance. Comparison of population estimates of smaller trout in the test area with those in control areas suggested that only large brook trout (> 229 mm) increased in abundance after predator removal; increased numbers of small brook trout (< 229 mm) and brown trout (< 305 mm) were not observed. Significant changes in age-specific length was not observed. Increased catches of brook and brown trout by sportfishermen could not be demonstrated. The authors concluded that removal of considerably more predators was needed to induce major changes in trout populations and in subsequent angler's catch.

This paper is relevant to the present study because it suggests by inference that factors other than predators influence fish populations, or that predation rates of surviving predators may increase after removal of some predators. Predator control may not produce expected results, therefore evalution of predation processes is important.

Smith, M.W. 1956. Further improvement in trout angling at Crecy Lake, New Brunswick, with predator control extended to large trout. Canadian Fish Culturist. 19: 13-16.

Brook trout, birds, Crecy Lake, New Brunswick, killing or frightening birds and large trout to improve survival of trout stocked for sportfishermen.

In this brief note, the author suggested that the removal of large predatory trout improved the survival of stocked fingerling trout which led to substantially greater catch rates of trout (from 0.5 to 3.2 fish per hour). These results were confounded by the fertilization of the lake during the years of investigation.

Smith, M.W. 1968. Fertilization and predator control to increase growth rate and yield of trout in a natural lake. Journal of the Fisheries Research Board of Canada 25: 2011-2036.

Brook trout, birds, Crecy Lake, New Brunswick, lake fertilization, killing or frightening birds, mammals, and eels to improve survival of trout stocked for sportfishermen.

Predator control in Crecy Lake, Canada, during 1951-1959 resulted in increased survival and reduced growth of brook trout. Maximum recapture rates in the sport fishery before and after predator control were 17% and 88% for yearling brook trout. Catch per effort improved with predator control. The effects of fertilization were less apparent.

The results of this investigation suggest that predator control may improve survival of the targeted species but greater survival could lead to reduced growth depending on their residency in the lake.

Steinberg, Lowell. 1989. National Marine Fisheries Service, Montlake Lab, Seattle, Washington, personal communication.

Squawfish, Columbia River, purse seining techniques.

Mr. Steinberg discussed several aspects of purse seining for squawfish in Columbia River. He recalled that his seines were only 8-12 ft deep and constructed of small-mesh web. Squawfish could be captured by the seine in deep water (> 12 ft). Good areas for capturing squawfish were near grain elevators where excess waste may have attracted squawfish. Hook and line fishing with lures (white nylon rope) was highly effective in the tailrace and forebay areas He caught a squawfish with nearly every cast. Squawfish seemed to be attracted to light at night; they would rise in the water column. He also caught many squawfish from -10 ft depth.

White, H.C. 1939. Bird control to increase the Margaree River salmon. Bulletin of the Fisheries Research Board of Canada 58: l-23.

Kingfisher, merganser,, char-fontinalis, Atlantic salmon, Northeast Margaree River, gun, control of fish-eating birds to improve Atlantic salmon smolt survival.

Over 880,000 salmon and trout were estimated to be consumed by kingfisher and merganser foraging on the Northeast Margaree River in 1935. Removal of the birds corresponded to a 120% increase in the number of migrating Atlantic salmon smolts relative to the previous year without predator control (see Huntsman 1941). The author warns that bird removal would also improve survival of smolt-eating char.

Willis, C.F. & others. 1985. Abundance and distribution of northern squawfish and walleye in John Day Reservoir and tailrace, 1982. Annual progress report, 1982. Oregon Department of Fish and Wildlife. 33 pp.

Squawfish, walleye, Columbia River, drift and stationary gill nets, trap nets, boat electrofishing, hook and line, radio, abundance and distribution of salmon predator populations.

A variety of gear types were used to access the abundance and distribution of squawfish and walleye in John Day Reservoir. Squawfish abundance in the boat restricted zones of John Day and McNary dams were approximately 4,600 and 8,500 fish, respectively. Walleye abundance could not be estimated because they were not recaptured.

Angling appeared to be the most effective method in capturing squawfish near the dams (2,100 fish caught, catch/h = -4 fish/h) relative to other gear types (670 fish caught, catch/h = < 1 fish/h). Beach seines (20 sets) were ineffective in capturing either species. Electrofishing tended to capture smaller fish, whereas angling captured squawfish >300 mm. Squawfish moved into the tailrace area after spilling stopped.

Wright, Sam. 1989. Washington Department of Fisheries, Olympia, Washington, personal communication (206-753-6600).

Squawfish, Chehalis River, Lewis River, Yakima River, squawfish abundance.

Wright noted that migrations of squawfish, apparently related to spawning, occur in the Chehalis River and tributaries, tributaries of the North Fork of the Lewis River above Merwin Dam, and the Yakima River. The Yakima River near the Prosser diversion has an extensive run of squawfish and suckers. High catch rates of squawfish could be made with seines or electroshocking.

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